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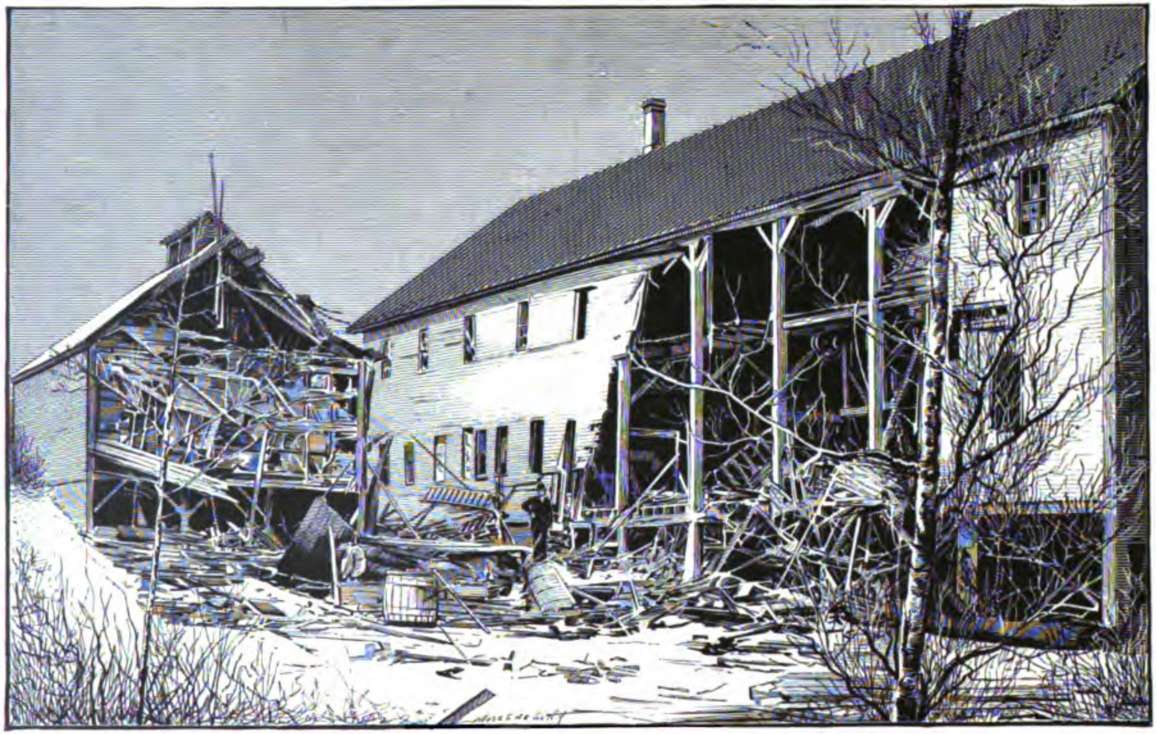
USEFUL THINGS TO KNOW ABOUT STEAM BOILERS.



Explosion at Bryant's Pond, Maine.

USEFUL THINGS TO KNOW

ABOUT

STEAM BOILERS.

COMPILED FOR

THE INFORMATION OF

OWNERS, STEAM USERS, AND ENGINEERS.

George Bates Nichols

BY

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PREFACE:

THE following pages were mostly compiled from various authorities, for the use of Owners, Steam Users, and Engineers, at the request of the American Steam Boiler Insurance Company of New-York.

This has no pretensions to be a compendious or exhaustive treatise, but is intended simply to afford some information in regard to the salient points of advantage or disadvantage offered by the different styles of boilers, to make better known the "modus operandi" of combustion in a boiler-furnace, the operations going on inside of a boiler (often resulting in corrosion and incrustation), and the best methods of managing and taking care of boilers.

There is a short explanation in regard to explosions, and such illustrations have been inserted as it is hoped will aid in the elucidation of the subjects treated upon.

Some useful miscellaneous facts, and some tables for shortening the labor of calculation, etc., will be found in the Appendix.

A list of the books more frequently consulted, and of which free use has been made, is annexed, to enable those so desiring to study the subject in its entirety.

Of course there is some original matter, but it forms only a small part of the whole.

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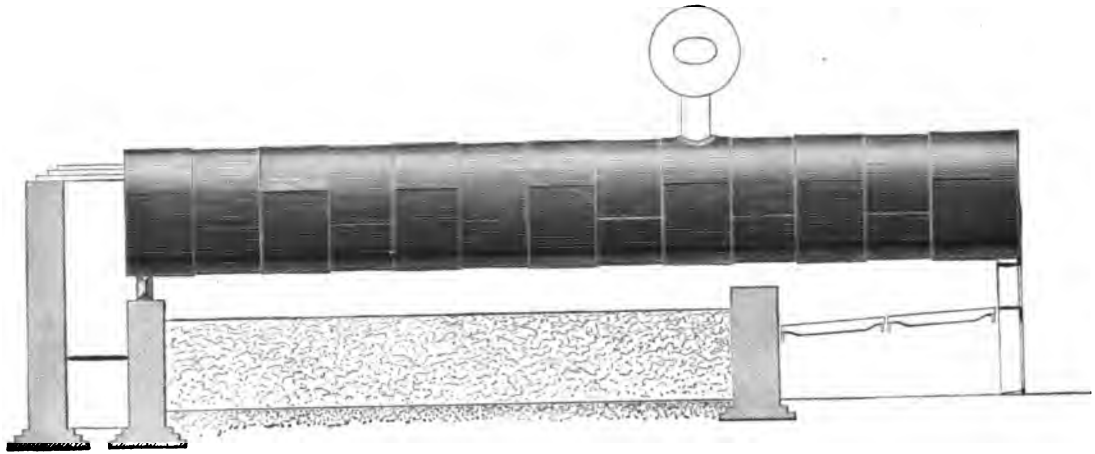


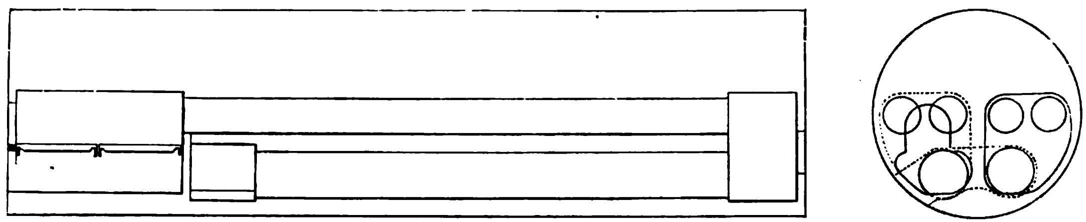
Cylinder Boiler.

BOILERS:

A STEAM-BOILER is a close vessel in which steam is generated by the application of heat, and provided with a suitable inlet for water and outlet for steam. It is constructed of various materials, iron, steel, and copper being generally used, and it is of widely different forms, that of a cylinder, however, being more generally preferred on account of its strength.

The prime requisites in a boiler are strength and durability, small bulk and weight, free circulation of the steam and water currents, efficiency of the heating surfaces, accessibility for cleaning and repairs, and suitable arrangements for insuring economy of fuel and prevention of smoke, especially when bituminous coal is used as fuel.

There are two classes of boilers—those having internal furnaces, and those whose furnaces are external; and, again, each of these may be subdivided into two sections—those in which the products of combustion pass through flues or tubes surrounded with water, and those in which the tubes contain water and are surrounded by the gaseous products. The varieties in most common use in this country are Plain Cylinder, Horizontal Tubular, Union, North River, Double Flue, Locomotive or Fire-box, Cornish, Marine



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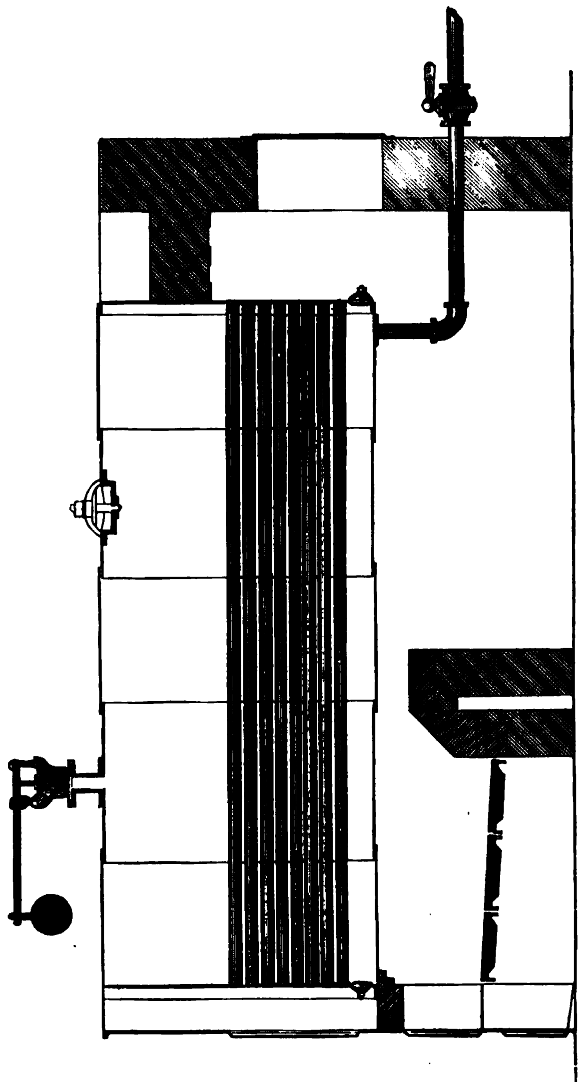
Return Drop Flue Boiler.

Tubular, Return Drop-flue, Upright Tubular, Lancashire, Martin's. There are many patent boilers possessing qualities of more or less value, but space is wanting to describe them.

Plain Cylinder Boilers were almost exclusively used in factories until within about twenty-five years. They afford the greatest facility of access for cleaning and repairs, and have a free circulation, but their heating surface is not so disposed as to give the greatest efficiency, and when their length is very great in proportion to their diameter, they are liable to great wear and tear from unequal expansion. Nowadays, their use is confined principally to iron works. They are fired externally, and are durable, but are not economical in the use of fuel.

Double Flue Boilers are plain cylinders having two flues of considerable size extending from head to head. They are set in brick-work in the same manner as Horizontal Tubular Boilers, and are fired externally, the gases passing underneath the shell to the rear of the boiler, where they enter the flues, traversing their length to the front of the boiler, where they enter the "breeching" and are led from thence into the chimney. These boilers are not so durable as the plain cylinder variety, giving out principally in the flues, but they are easily cleaned, and have a good circulation, though they are not so strong as a plain cylinder; they are, however, the favorite boiler for planing and saw mills. Like the cylinder variety, they require considerable floor space, yet with



Horizontal Tubular Boiler.

very bad feed-water the use of one of these two varieties is almost necessitated. This variety is more economical in fuel than the plain cylinder, but its first cost is greater, and it is more difficult to repair.

THE DROP-FLUE BOILER is very economical in fuel, but, like the two preceding varieties, it has the disadvantage of needing considerable floor space. It has an internal furnace, and flues lead from this furnace to a chamber at the back end of the boiler, called the back connection, and from the lower part of this chamber return flues lead to a chamber just behind the bridge, which in these boilers is a water-bridge; and an opening from this front connection, as it is called, permits the gases to pass along the outside of the bottom of the boiler to the rear again, where there is generally a brick flue in direct connection with the chimney. This arrangement of flues gives a long run for the gases, allowing time for their thorough combustion; but this boiler is not so accessible for cleaning or repairs as either of the two varieties already mentioned, and they are not so strong nor so durable, nor is the circulation quite so good; and the first cost is much greater.

A HORIZONTAL TUBULAR BOILER has a cylindrical shell, with tubes extending from head to head. It is fired externally, and, as the tubes act as extinguishers of flame, it is necessary that the combustion of the gases be entirely completed before they reach the tube sheet. It generates steam more rapidly than either of the varieties before mentioned; is not quite as economical in

Fire-box Boiler.

fuel as a drop-flue boiler; its circulation is imperfect, and it is not so easily accessible for repairs as the two first varieties mentioned, or for removing scale and deposit from its interior; but it occupies much less space than either of the other varieties, and is strong and durable.

A Locomotive or Fire-box Boiler is not generally noted for its economy, but it is capable of generating a great amount of steam, and it occupies comparatively small space. It is internally fired; its circulation is generally defective; it is not easily accessible for cleaning, but it requires no masonry; and recent improvements, such as brick arches in the furnace and a combustion chamber, have much increased its economy. From its being self-contained, so to speak, it can be mounted on wheels and removed from place to place as may be required. It is strong and durable when well cared for, provided the water-legs are not too narrow and are kept free from scale and deposit.

An Upright Tubular Boiler of any great power is seldom used. It is wasteful of fuel, and though it occupies small space, being internally fired, and therefore requiring no masonry, yet it is subject to strains that produce defects requiring frequent repairs. It can generate steam rapidly, and can be easily mounted on wheels and transported where needed. It is not a durable boiler, and is not accessible for examination and cleaning although it is strong.

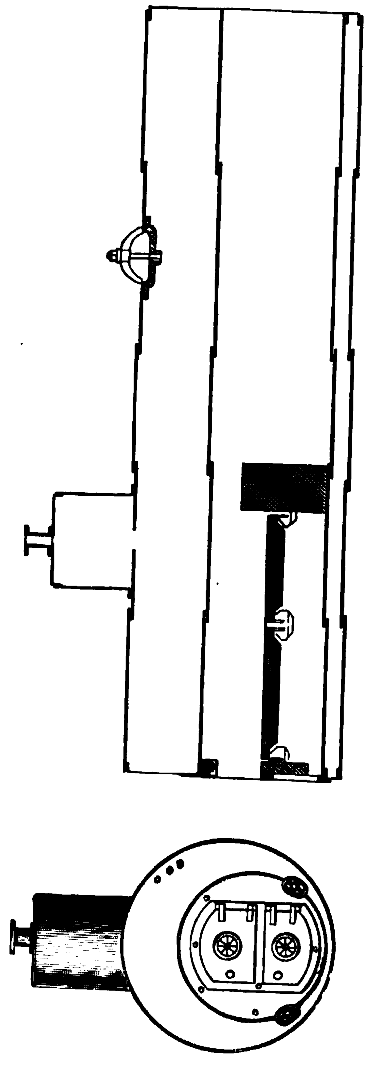
A Cornish Boiler is cylindrical in form and has one large flue extending through it from head to head;


Upright Tubular Boiler.

the furnace is in one end of this flue, a brick bridge being built in the flue at the end of the grates. The gases, after passing through the flue, wind back and forth through flues in the masonry along the sides and under the bottom of the boiler. With slow combustion it is very economical, and, if the flue is made with the Adamson expansion joints, it is strong and durable, and it is accessible for cleaning and repairs, while the circulation is very good; but, like other varieties before mentioned, it takes up considerable floor space.

THE LANCASHIRE BOILER is merely a double-flued Cornish boiler, and possesses about the same advantages and disadvantages. In both of these boilers a series of inverted conical tubes are often inserted in the flue, behind the bridge, at right angles to its axis, both vertical and inclined. These tubes are water-tubes, and serve the double purpose of stays and additional heating surface, besides increasing the circulation of the water currents. They also increase the efficiency of the boiler, and promote economy of fuel. These are known as Galloway Tubes.

THE UNION BOILER, so called, consists of two cylindrical boilers, lying one above the other horizontally and parallel, and connected by short vertical wrought-iron necks. The lower cylinder is filled with tubes extending from head to head; the upper one has no tubes, serving more as a steam drum than a generator. The economy of this boiler is not remarkable; it is not easily accessible for repairs, as the lower shell cannot be internally examined or freed from incrustation, and it possesses no superiority



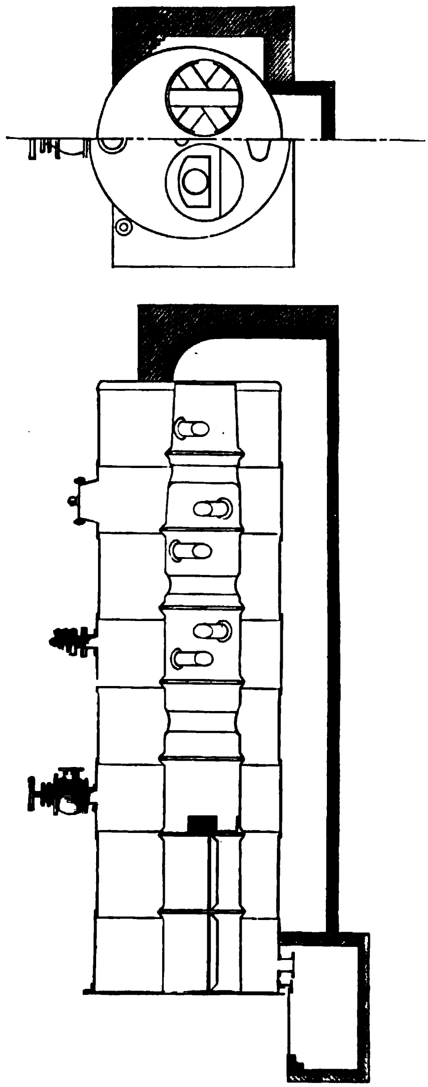
Cornish Boiler.

over any boiler before mentioned, while from unequal expansion it is liable to rupture at the flanges of the connecting necks, and the necks themselves are very liable to internal corrosion.

THE NORTH RIVER BOILER is used on steamboats generally around New-York City and the Eastern States. It has usually two rectangular internal furnaces without water bottoms. There is a water bridge at the back of the furnace over which the products of combustion pass into a combustion chamber and then are led by flues, in the lower part of the shell, into a back connection, thence rising and passing through another set of flues into the bottom of the steam chimney near the back end of the furnaces above the combustion chamber. The sides of the furnaces present flat stayed surfaces. The external form of the boiler is that of a cylinder with a rectangular block inserted at the bottom of one end. Some parts are not accessible for examination or repairs, although it is a moderately durable boiler, but is not suited for carrying pressure exceeding forty or fifty pounds.

THE MARINE TUBULAR BOILER is cylindrical in form, with flat ends, and is especially designed for carrying steam of high pressure. It is used with all compound marine engines. It is strong and durable, fairly accessible for cleaning and repairs, is economical in fuel, but it is rather defective in circulation.

MARTIN'S WATER-TUBE BOILER was at one time used very extensively in the vessels of the United States Navy.



Lancashire Boiler, with Galloway Tubes.

It is rectangular in form, but limited in strength — 30 lbs. being as much pressure as it ought to be called upon to sustain; but it is durable and accessible for cleaning and most repairs; repairs to the tubes, however, necessitate the emptying and cooling of the boiler. It has been superseded by the modern marine boiler, owing to the use of compound engines and the high pressure of steam called for, but it has not been surpassed for economy of fuel and efficiency as a steam generator. Reference to the accompanying plates may give a more correct idea of the distinctive features of the various boilers named.

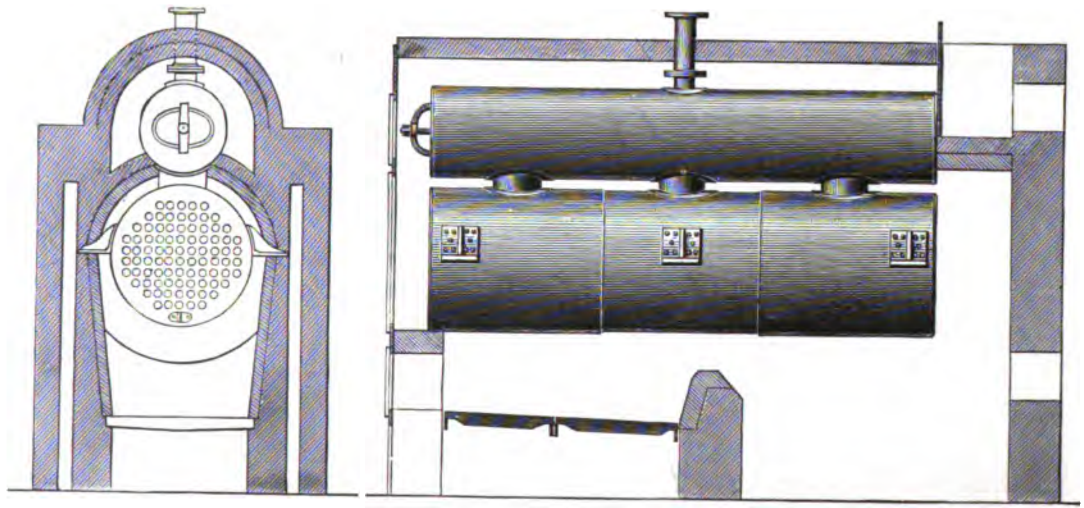
Boilers, cylindrical in shape, should be braced from head to head, and no brace should be subjected to a greater strain than 6000 lbs. per square inch of section.

Staying the heads to the shell by angular braces is not the best practice, more especially when the braces all foot on one course.

When domes are used on boilers, instead of angular bracing, the dome head should be braced to the shell directly, and the hole, cut through the shell, should be no larger than sufficient to allow a man to pass through easily, and should be reënforced by a strong ring of wrought iron.

The frames for the man-hole plates, if of cast iron, should be heavy and of the best material, as they sometimes crack through, and an explosion is the result.

It is not a commendable practice to make the fire-sheets of a boiler of a different quality of iron from the remaining portion of the shell, as unequal expansion and contraction are thereby induced.



Union Boiler.

All flat surfaces should be carefully stayed, and the stays should be of such size that their distances between centers will not be enough to allow of buckling of the plates.

There is a great difference of opinion as to the comparative merits of machine and hand riveting; machine-riveting, properly done, is decidedly superior to hand-riveting on the average; but all machines don't do their work alike well, and the best hand-riveting is superior to the work done by some machines.

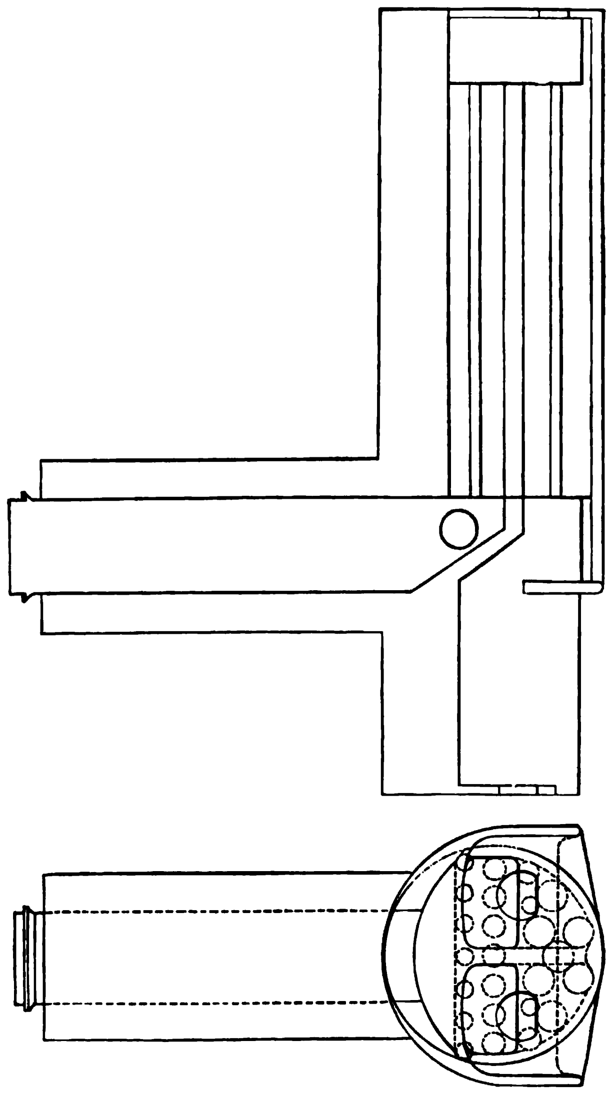
The holes for rivets in steel plates should be drilled, or else they should be punched three-sixteenths of an inch less in diameter than the rivet, and afterward reamed to the full size.

The plates of a boiler should all be planed on their edges to the proper bevel before they are put together, to avoid breaking the skin of the iron by subsequent chipping preparatory to calking, and for the same reason care should be taken that the point of the calking tool is properly shaped *and kept so.*

Long flues should be stiffened and strengthened at intervals by rings or hoops of angle iron, or, better still, by flanging the ends of two consecutive courses, inserting a flat ring between the flanges, and riveting them together. This acts as an expansion joint, and adds greatly to the strength of the flue and durability of the boiler.

Hand-holes should be cut at the bottom of both the front and back heads of a horizontal boiler, to allow of thorough examination and the removal of deposit.

The rivet holes in every course should come fair, or otherwise the strength of the joint is impaired, and it is liable to leakage.



North River Boiler.

Socket bolts should be perpendicular to both the flat surfaces which they connect—as any considerable deviation will inevitably cause serious leaks.

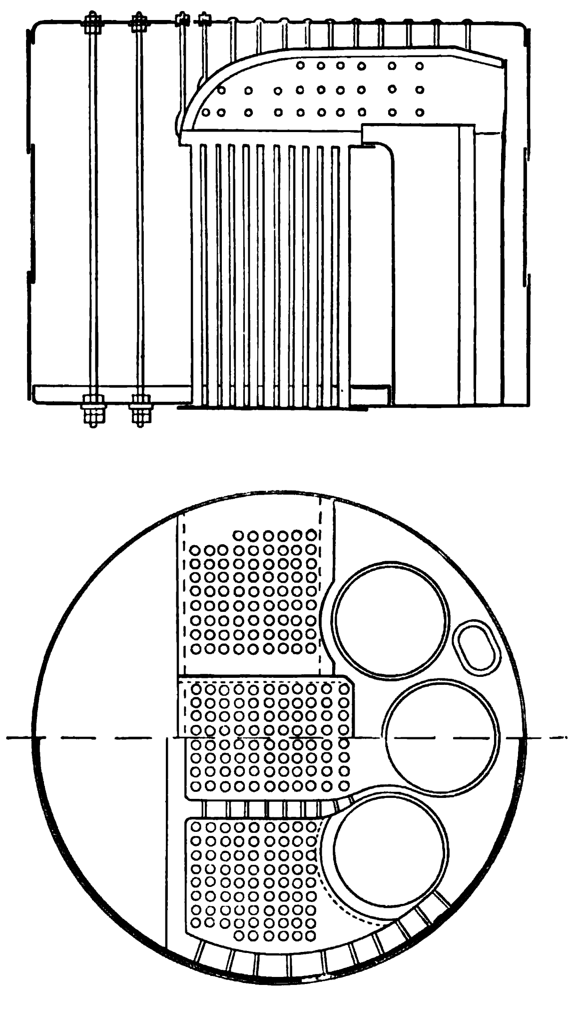
Nothing but the best material and workmanship in the construction of a boiler should ever be allowed, and the same rule should obtain in regard to the fittings, and to the setting especially.

The practice of setting boilers in nests, or batteries, of two, three, or four boilers is not advisable, as an accident to one necessitates the disuse of the others in that battery. And I would remark that it is well to have one or more reserve boilers, to facilitate the keeping of the whole plant in good repair and condition. Under good management, with spare boilers, at least fifty per cent. is added to the life of the plant.

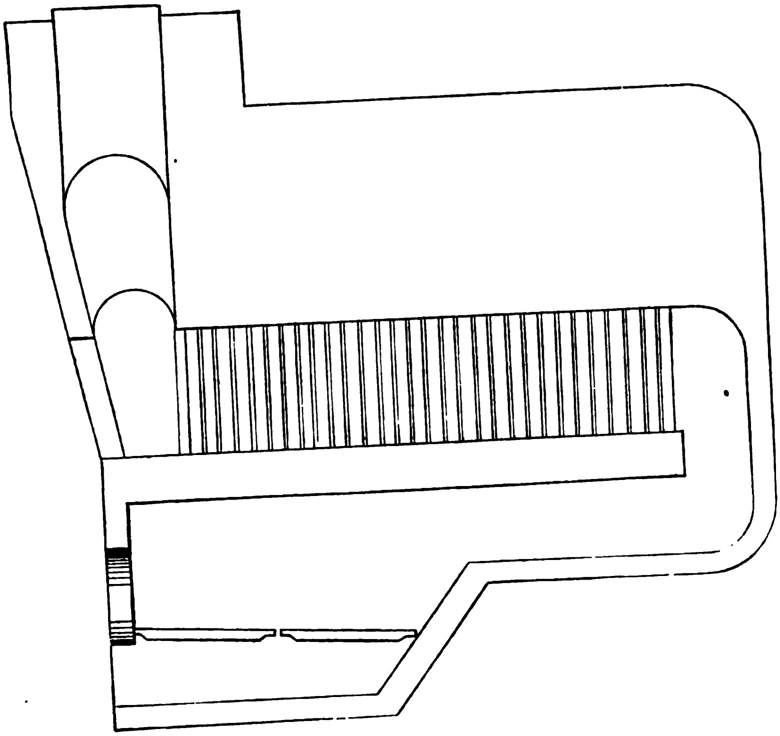
It should not be forgotten that short boilers do more work in proportion than long ones, and also that they strain léss, and are, therefore, less liable to require repairs.

As regards riveting, the horizontal seams should always be double riveted and staggered, but the girth, roundabout, or transverse seams, as they are indifferently called, may be single, as double riveting them merely adds to the weight and cost without a corresponding necessary increase of strength.

Land boilers should always be set at an inclination of one-half inch to every ten feet of length, to admit of more perfect drainage, and for the same reason the blow-off pipe should lead from the under side of the shell of the boiler.



Modern Marine Boiler.



Martin's Water-tube Boiler.

COMBUSTION:

ECONOMICAL generation of steam in boilers depends upon several distinct conditions, viz.: perfect combustion of the fuel; a proper disposition of the clean surfaces to receive and transmit the heat to the water; a uniform supply of feed water at a high temperature near the water-level; and also the arrangement and proportion of the various parts of the boiler, so that the water and steam currents shall neither interfere with each other nor be obstructed in their free course.

Without perfect combustion a great portion of the heat, which the coal or other fuel is capable of giving out, is not developed, and hence loss results. If the surfaces are not properly adapted for the reception of the heat given out by the fuel, the gases pass into the chimney at too high a temperature, with loss again. Heating the feed water by waste steam, or waste gases, leaves less to be done by the fuel in the furnace, and by introducing the feed near the water-level; less contraction and expansion of the plates occur, which is a fruitful source of expense. And if a boiler is so constructed that the steam and water currents in ascending and descending interfere with each other, or if the configuration of the parts ob-

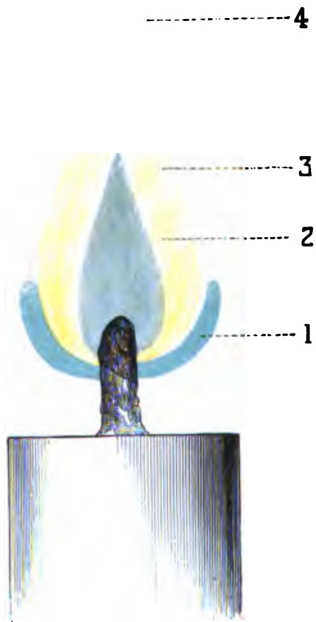


Plate I.

structs their proper motion, foaming, overheating, burning of plates, etc., result, causing great expense for repairs.

Combustion is an energetic chemical combination of oxygen with some substance, accompanied by light and heat. The substance with which it combines is called the combustible, or, when the combustion takes place in a furnace, stove, or grate in the ordinary use of every-day life, it is generally called fuel,—as, for instance, wood, charcoal, coke, coal, oil, etc.

The oxygen is supplied from the atmosphere by which we are surrounded. Air consists of two gases, nitrogen and oxygen, of which the oxygen forms only one-fifth part in bulk, the gases not being in a state of chemical combination, but forming a mixture only.

In the flame of a common candle, combustion takes place in the following manner:

The wick is filled with tallow, wax, or other oleaginous material, and, on a match being applied, this material is converted into gases which ignite, forming flame. This flame is divided into four distinct portions, or coatings, differing both in their aspect and the nature of the processes producing them.

Immediately surrounding the wick is a dark space (1) of a conical shape, filled with the combustible gas unconsumed, and continually generating by the first action of the heat upon the fuel (wax, tallow, etc.)

Surrounding the base of the dark cone and the lower portion of the luminous part is a cup-shaped cone (2) of a blue tint, faintly luminous but sharply defined. It results from the sudden and complete combustion of the

gases of the dark cone (carburetted hydrogen principally) with a full supply of air (oxygen) striking them from without.

Above the dark cone lies the luminous portion (3) of the flame, the oxygen of the air uniting with the hydrogen, and raising the now separated carbon to the high temperature of incandescence which gives the luminosity to this portion of the flame.

Exterior to all is the cone of final and complete combustion (4), in which the highly heated carbon atoms unite with oxygen in a combustion of their own, being converted into carbonic acid. This cone (4) is only faintly luminous, it surrounds the flame on all sides and is its hottest portion. The maximum temperature is a little *above* the point of the luminous cone, where we also find the highest *oxidizing* power, while just *within* the luminous point the high temperature and the presence of free carbon coöperate to produce the most energetic *reducing* action.

The products of perfect combustion are thus shown to be water (steam) and carbonic acid, and, to insure it, a sufficiently high temperature, and a sufficient supply of oxygen are necessary.

The first step towards effecting the combustion of any gas is to ascertain the quantity of oxygen with which it will chemically combine, and the quality of air required to supply that amount of oxygen.

Much of the apparent complexity which exists on this head arises from the disproportion between the relative *volumes*, or *bulk*, of the constituent atoms of the several

gases, as compared with their respective *weights*. For instance, an atom of *hydrogen* is *double* the bulk of an atom of *carbon vapor;* yet the latter is *six times the weight* of the former.

Again, an atom of hydrogen is *double* the bulk of an atom of oxygen; yet the latter is *eight times the weight* of the former.

So of the constituents of atmospheric air — nitrogen and oxygen. An atom of the former is *double* the bulk of an atom of the latter; yet, in weight, it is as fourteen to eight.

Hydrogen, separating from its combination with carbon (carburetted hydrogen), on the application of heat, and uniting with oxygen, produces water in the shape of steam, and this atom of steam occupies a bulk only two-thirds of that of both — as below:

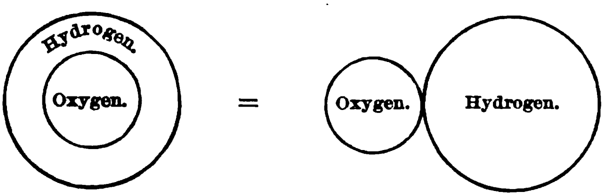


FIG. 1.

Again, the carbon meeting with its equivalent of oxygen, unites with it, forming carbonic acid gas composed of *one atom* of carbon (by weight 6), and *two atoms* of oxygen (by weight 16), the latter in volume being double that of the former, as in the annexed figure:

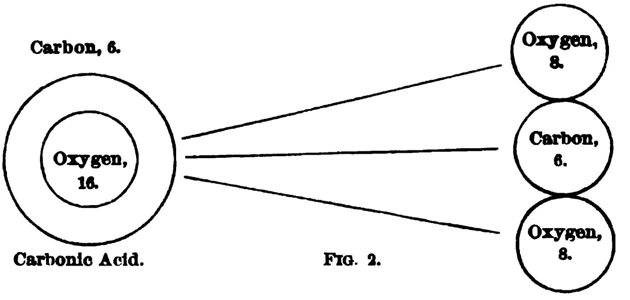


FIG. 2.

Carburetted Hydrogen is composed of *two atoms* of hydrogen (by weight 2), and *one atom* of carbon vapor (by weight 6); and their resultant bulk is that of one atom of hydrogen only, as in the annexed figure:

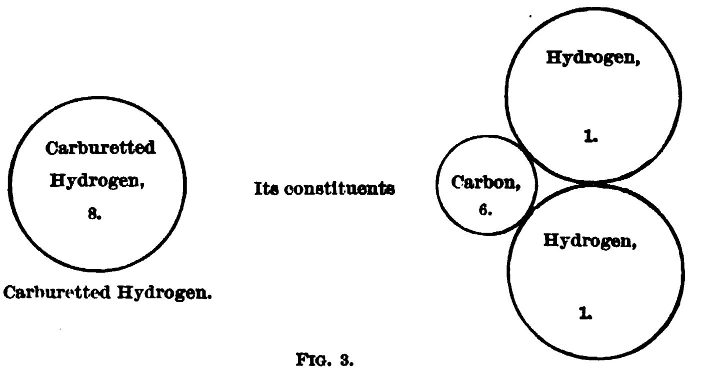


FIG. 3.

Atmospheric air is composed of two atoms of nitrogen and one atom of oxygen; each of the former being double the volume of an atom of the latter, while their relative weights are as fourteen to eight. But this is only a mechanical mixture, the nitrogen not being in chemical

combination with the oxygen: the gross weight of the nitrogen is to that of the oxygen as twenty-eight is to eight, and the gross volume as four to one, as in the annexed figure:

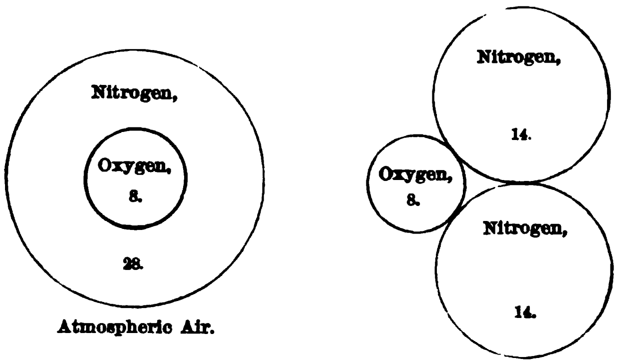


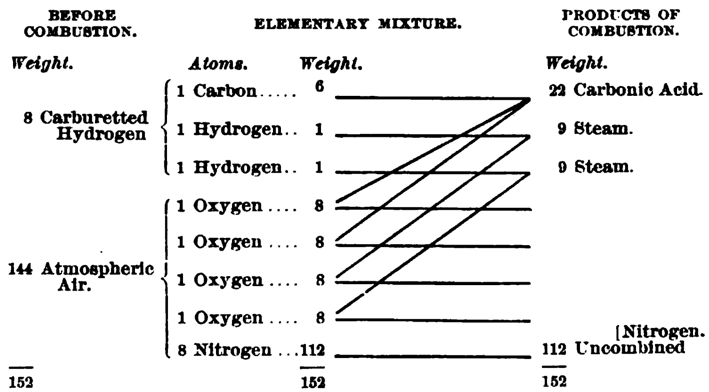
FIG. 4.

Now, having ascertained the quantity of *oxygen* required for the saturation and combustion of the two constituents of carburetted hydrogen, the remaining point to be decided is, the *quantity of air that will be required to supply this quantity of oxygen.*

This is easily determined, as we know precisely the proportion which oxygen bears, in volume, to that of the air. For as oxygen is but *one-fifth* the bulk of the air, *five* volumes of the latter will be necessarily required to produce *one* of the former; and as we want *two* volumes of oxygen for each volume of the gas, is follows that, *to obtain these two volumes, we must provide ten volumes of air.*

The annexed diagram shows the volume of air required for the combustion of the gas.

CARBURETTED HYDROGEN.



Now, when burning bituminous coal, after the gas has been consumed, there still remains the carbonaceous part, coke, resting upon the bars, to be disposed of.

Carbon is capable of being united with oxygen in two proportions, by which two distinct bodies are formed, possessing distinct chemical qualities.

The proportions, in which carbon unites with oxygen, form first, *carbonic acid;* second, *carbonic oxide.*

Carbonic *acid,* we have seen, is a compound of one atom of carbon with two atoms of oxygen; while carbonic *oxide* is composed of the same quantity of carbon with but *half* the above quantity of oxygen, as in the annexed figures:

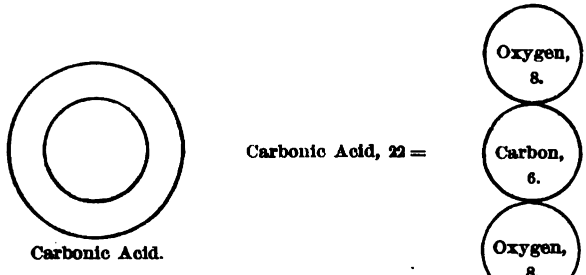


FIG. 5.

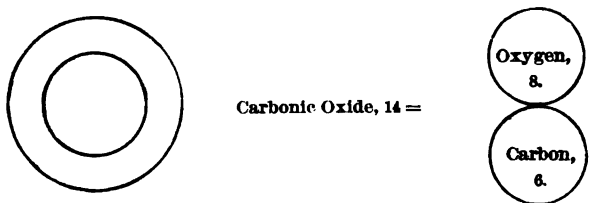


FIG. 6.

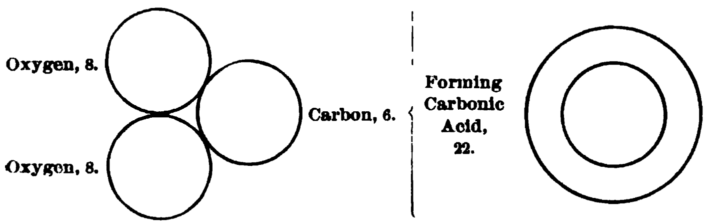
Here we see that carbonic *oxide*, though containing but *half* the quantity of oxygen, is yet of the same volume as carbonic acid, a circumstance of considerable importance on the mere question of *draught*, and supply of air, as will be shown hereafter.

Now the combustion of this *oxide, by its conversion into the acid*, is as distinct an operation as the combustion of the carburetted hydrogen, or any other combustible.

But the most important view of the question is as regards *the formation* of this *oxide;* and this is the part of the inquiry which most requires our attention.

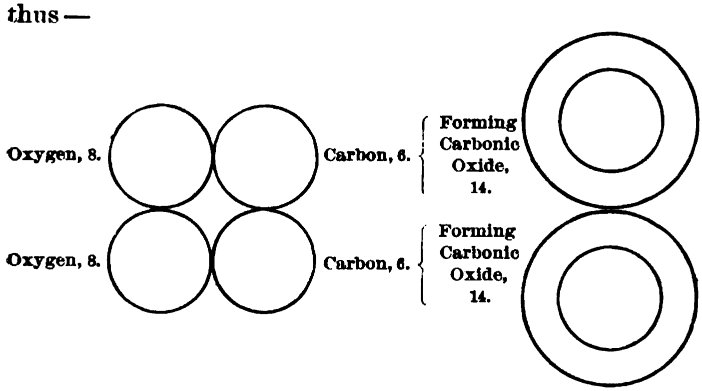
The direct effect of the union of carbon and oxygen is the formation of carbonic *acid.* If, however, we *abstract*

one of its portions of *oxygen*, the remaining proportions would be those of carbonic oxide. It is equally clear, however, that if we *add* a second portion of *carbon* to carbonic *acid*, we shall arrive at the same result, namely, the having carbon and oxygen combined in equal proportions, as we see in carbonic *oxide*.



Carbonic Acid. FIG. 7.

By the addition, then, of a *second* portion of carbon to the above, two volumes of carbonic *oxide* will be formed, thus —



Now, if these two volumes of carbonic oxide cannot find the oxygen required to complete their *saturating* equivalents, they pass away necessarily but *half consumed*, a cir-

cumstance which is constantly taking place in all furnaces where the air has to pass through a body of incandescent carbonaceous matter.

The most prevalent operation of the furnace, however, and by which the largest quantity of carbon is lost in the shape of carbonic *oxide*, is thus: The air, on entering from the ash-pit, gives out its oxygen to the glowing carbon on the bars, and generates much heat in the formation of carbonic acid. This *acid*, necessarily at a very high temperature, passing upwards through the body of incandescent solid matter, takes up an additional portion of the carbon, and becomes carbonic *oxide*.

Thus, by the conversion of one volume of acid into two volumes of *oxide*, heat is actually absorbed, while we also lose the portion of carbon taken up during such conversion, and are deceived by imagining that we have "burned the smoke."

Another important peculiarity of this gas (carbonic oxide) is, that, by reason of its already possessing *one-half* its equivalent of oxygen, it inflames at a lower temperature than the ordinary *coal* gas; the consequence of which is, that the *latter*, on passing into the flues, is often cooled down below the temperature of ignition; while the *former* is sufficiently heated, even after reaching the top of the chimney, and is there ignited on meeting the air.

We may thus set it down as a certainty, that, if the carbon, either of the gas or of the solid mass on the bars, passes away in union with oxygen in any other form or proportion than that of *carbonic acid*, a commensurate loss of heating effect is the result.

Now, in order to kindle a substance and keep it burning, it must be heated to a certain degree and kept up to that temperature.

The phosphorus of a match inflames so readily, that mere friction ignites it, and in burning it gives out heat enough to ignite the sulphur of the match, which in turn ignites the wood of the match — and by means of this last flame we ignite the kindlings, and they in turn ignite the larger pieces of wood, and the heat given out raises the temperature of the coal sufficiently for it to ignite, and thus we see that ignition of coal is the last of a series of progressive steps — each increasing in temperature.

Smoke is a sure evidence of imperfect combustion, but, as we have seen, it does not necessarily follow that where there is no smoke combustion is perfect.

In combustion the heat must be referred to the chemical union of the substances and the luminosity to the high temperature.

A jet of coal gas exhibits all the phenomena already described in regard to the flame of a candle; but, if the gas be previously mingled with air, or if air be forcibly mixed with, or driven into, the flame, no separation of carbon occurs, the hydrogen and carbon burn together, and the illuminating power almost disappears. Pure flame always emits a feeble light.

The perfect combustion of coal in a furnace can only be effected by a sufficient supply of oxygen, contained in the air, in a proper manner. To illustrate, suppose we have the fire lighted and steam raised in an ordinary wood-burning locomotive, and we throw into the furnace about

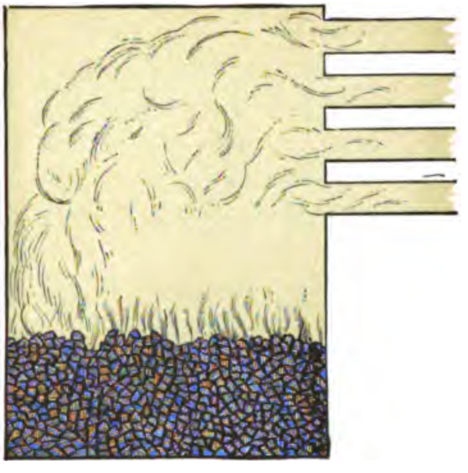


PLATE II.

500 pounds of bituminous coal; now, the engine being in motion, we shall observe some or all of the following results:

For a few minutes, the flame in the fire-box will be darkened or nearly extinguished, the steam pressure falls, and a dense cloud of smoke and sparks come from the chimney.

After a little while, the fire becomes bright, the amount of escaping smoke diminishes, and the steam-pressure rises and attains its maximum.

There is now a strong local heat in the furnace, the temperature being higher than with wood. After a while, the grate, perhaps, becomes clogged with clinker, and the surface of the fire, which at first had swelled as the coal was ignited, sinks in a crust of greater or less thickness.

If we allow the fire to burn down, and stop the engine, we shall find the tubes coated with soot and considerable fine coal in the smoke-box.

We find, on opening the fire-door soon after placing coal on the fire, that the smoke will be diminished both in quantity and intensity, although the steam pressure will fall, showing that the furnace is cooled by the admission of the air. Also the smoke which escapes from the chimney will deposit soot on any surface, as a piece of white paper, exposed to it. But the dense vapors formed in the fire-box will not, as they leave the coal, deposit any soot. So that, whatever may be the resemblance between the dark vapors, as distilled from the coal, and the smoke at the chimney-top, they differ at least in one respect.

Again, the dark vapor in the furnace ignites and gives out flame as the air gains access to it, while the smoke, once formed, cannot be burned by any practicable process — by heating, mixing with air, or otherwise. But while this vapor, which we shall now call gas, may be burned, it is not of itself combustible. If we fill a jar with this gas without admixture of air, a lighted candle, thrust into it, will be immediately extinguished. In ordinary gas-works, the same kind of gas is expelled from coal in cast-iron retorts heated to redness. It will burn only in contact with air. Now, while this gas burns regularly and silently when allowed to come into gradual mixture with the air,— precisely as the same kind of gas burns in an ordinary illuminating burner,— yet this same gas, *previously mixed* with about nine times its weight of air, will, when subsequently ignited, explode like gunpowder.

By "shutting off" steam from the engine, or closing the damper, the smoke is much increased; yet the only direct effect of the manipulation is the exclusion of air from the fire.

If a close jar be filled with the coal-gas, and a jet of air be led into it, the jet of air can be ignited and will burn in the jar, exactly as a common gas-jet will burn in the air. The combustion of either is simply its chemical combination with the other.

While the gas is being expelled from the coal, the latter remains at a low heat — no particle of solid coal (or, rather, coke) can burn while gas is issuing from it. This, of course, refers to coal in its respective particles, as a *lump* of coal may be giving out gas in one place while

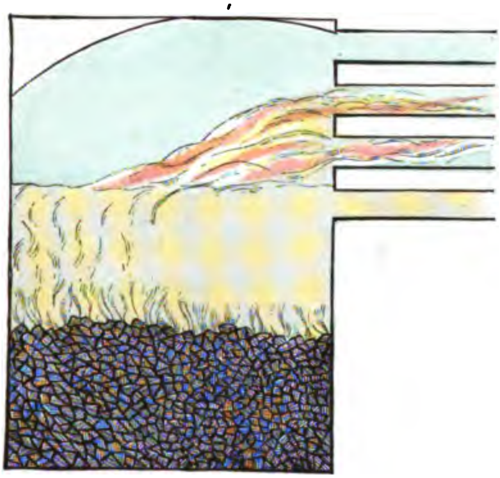


PLATE III.

all has been expelled from another, and the remaining coke already ignited.

This precedence in the burning of the gas is proved in making coke or charcoal. By admitting just sufficient air for the combustion of the gas in the raw fuel, this gas only is burned, and the coke, or charcoal,—pure carbon,—is left behind. Were it not for this distinction in nature, we could not manufacture either coke or charcoal except by distilling the gas from the raw fuel in *close vessels*, and by the consumption of a considerable quantity of additional fuel in producing a high external heat.

As coke does not produce smoke in burning, the smoke issuing from our experimental engine must be generated from the gas in combinations, which it forms before reaching the chimney. The duration of smoke, therefore, measures the time during which the gas is distilling from the coal.

If we examine closely, we shall find that flame never enters a tube of ordinary size ($1\frac{3}{4}$ to 3 inches) for more than a few inches from its mouth.

No matter how near the tubes are placed to the surface of the fire, the flame is extinguished immediately on entering them. Flame, as has been shown before, is superficial, and is *stripped*, so to speak, of its air on entering a small tube; and hence the core, or central body of gas (which, by its bulk, gave diameter to the flame), passes through unconsumed. No flame whatever can pass *through* a tube. An unignited compound, known as carbonic oxide, may pass through, and, having a low

3

igniting temperature, may afterward take fire, and burn on coming to the air at the chimney-top. (The blue flame attending the conversion of carbonic oxide into carbonic acid is not, however, the flame we have to deal with in the furnace.) Hence, all the combustible matter contained in the flame at the moment of its extinction is lost, as it can only impart its full heat by its complete combustion.

The intensity of heat from coal or any other fuel burned in air is a fixed and inevitable degree for each kind, and depends on the nature of its constituents.

By the perfect combustion of seasoned wood (which, however, contains about twenty per cent. of water), the resulting heat is 2867° Fahr.; bituminous coal, of average composition, 4082°; anthracite coal, 4170°; dry coke, or charcoal, 4352°.

As long as water is in actual contact with the furnace sheets, there is hardly any heat which can burn out the metal. Water may be boiled over a fierce fire, when contained in a vessel the bottom of which is made of card-paper, or it may be boiled in an egg-shell, and in neither case will the material of the vessel be injured.

In our experimental locomotive, with water-spaces of, perhaps, not much more than two inches in width, we will find, by inserting a gauge-cock opposite the level of the surface of the coal, that water, if it issues at all, will do so intermittently when there is a very hot fire. This will account for much of the difficulty of burning out furnaces.

The effect of clinker and crust on the surface of the fire is to prevent the passage of air. The clinker is mainly sand or clay, vitrified or reduced by heat, and sometimes

mixed with mineral oxides, which by their fusion still further increase its amount and strength. The quantity of clinker depends entirely upon the cleanliness of the coal. The only specific against its effects is to keep it well broken and cleared out. It is well to note, also, that the volatilization into gas abstracts considerable heat from the burning coal—the steam generally falling on the application of fresh coal to the fire.

The combustion of coal seems to be yet, to a great extent, a mystery even with those who profess to understand it, as appears from the contradictory plans proposed to effect complete combustion.

Chemistry, however, in a few simple principles, unfolds the whole philosophy of combustion.

Coal is a compound substance, and may be decomposed by heat into several distinct elements. As far as regards combustion we have to deal principally with two of these only, viz.: Carbon, in the form of *coke*, and hydrogen, generally known as "*gas*." These two elements practically contain the full heating properties of the coal. If we do not obstruct the processes in which they enter into combustion, they will naturally be completely burned, and consequently will impart their full measure of heat and will make no smoke.

Now, what is the operation of "burning"? We say that when coal is thrown upon a fire it begins to "burn." But *before* any burning can possibly commence, the coal must suffer the preparatory process of decomposition. Its constituent elements must be separated, and then a regular order of precedence obtains in their combustion.

The burning which then takes place is this: the gas, which, having been distilled, burns first, does so merely by its chemical union with the invisible oxygen of the air, forming water (or steam). The gas having been burned, the coke takes its turn, and burns in exactly the same manner by combination with air, forming carbonic acid.

The combustion of the elements of coal in air is a mutual process, as is proved by the fact that neither of these by itself can possibly be burned. Flame itself is only the continuous explosion of successively combining atoms of air and gas, and which, had they been mixed previously in any considerable quantity, would detonate in the furnace like gunpowder, or with the force of a steam-boiler explosion. It is simply because this very mixture requires *time* for its accomplishment that the explosion can only go on by successive atoms, *thus forming continuous flame.* This influence of time must be kept distinctly in view, as it also determines, in a vital manner, the question of the combustion of coal in steam-boiler furnaces. It is only in the condition of flame, in the natural process of combustion, that the gas and air can develop their useful heating power.

Now, if the gas does not have sufficient time to enter into complete mixture, atom by atom, with the air while *both* are within the range of an igniting temperature, they pass away unconsumed, their value is lost, and they will produce *smoke.*

Coal is practically a solid compound of carbon and hydrogen. The carbon, so long as it remains as such, is

always solid and visible; the hydrogen, when driven from the coal by heat, carries with it a portion of carbon, the gaseous compound being known as carburetted hydrogen. A ton of 2000 pounds of average bituminous coal contains about 1600 pounds, or 80 per cent. of carbon; 100 pounds, or 5 per cent. of hydrogen; and 300 pounds, or 15 per cent. of oxygen, nitrogen, sulphur, sand, and ashes. But if this coal be *coked*, the 100 pounds of hydrogen driven off by heat will carry about 300 pounds of carbon in combination with it, making 400 pounds, or nearly 10,000 cubic feet of carburetted hydrogen gas. Thus, but 1300 pounds of carbon (65 per cent. of the original coal) will be left, and, with the earthy matter,—ashes, sulphur, etc., retained with it,—the coke will weigh but about 1350 or 1400 pounds—67½ to 70 per cent. of the original coal.

Thus, for every 2000 pounds of coal we have about 1300 pounds of solid carbon and 400 pounds of carburetted hydrogen to be burned, the remaining 300 pounds being waste—partly gaseous and partly solid.

As we have seen, the combustion of this matter is simply its chemical combination with the oxygen of the air, as the nitrogen merely passes unchanged through the fire, effecting nothing but an abstraction of heat. The carbon and carburetted hydrogen in burning will each combine with oxygen in fixed proportions only, the proportions being known as chemical equivalents.

What we have to do then is *to permit, and not to obstruct the access of air* to the coal, this access of air being permitted under such circumstances as shall *favor* its complete combination.

The only proportions in which carbon and hydrogen combine with air in combustion are these:

For every pound of carbon (pure coke) twelve pounds, equal to 159½ cubic feet of air, are required to supply the necessary oxygen to combine intimately with it.

For every pound of hydrogen, thirty-six pounds, equal to 478½ cubic feet of air, are required for similar combination. Thus for every pound of carburetted hydrogen gas, being one-fourth pound of hydrogen, and three-fourths pound of carbon, eighteen pounds, equal to 239¼ cubic feet, of air are required to supply the necessary oxygen.

Now, for every 2000 pounds of coal burned, the 400 pounds of carburetted hydrogen—the "gas"—requires 95,700 cubic feet of air, at ordinary temperature, and the 1300 pounds of solid carbon require 207,350 cubic feet of air. Practically, the "gas" from a ton of ordinary bituminous coal requires 100,000 cubic feet of air for its combustion, while the remaining coke requires 200,000 feet. Thus the gaseous matter of coal requires one-half as much air as is taken up by the solid coke. Where these combinations are completed the combustion is perfect. A given quantity of gas, completely burned, cannot produce smoke, since smoke contains a quantity of unburnt matter, and is in itself a proof of incomplete combustion. The products of perfect combustion are invisible, being for carbon and oxygen, carbonic acid; and for hydrogen and oxygen, invisible steam which condenses into water.

A coal-burning furnace is simply a vessel in which given elements are to be chemically combined in definite proportions. So far as the structure of the furnace may

aid these combinations, by giving room, direction, and time for their completion, so far will the furnace be efficient in burning coal completely, which is the same as burning it economically.

Among the most essential provisions in the arrangement of the furnace are those which operate to induce or solicit the mingling of the coal-gas and air. Both these are to be burned, neither can burn without the other, they can only burn together. Thus wherever the air is to be admitted, whether through the grates or through the openings in the door, the admission spaces should be small and numerous, so as to present as many surfaces of contact as possible. By diminishing the size and increasing the number of air spaces, we increase the surface of contact of the gas and air, just as, by diminishing the size and increasing the number of boiler tubes, we increase the surface of water exposed to heat. This increase of combining surfaces within a given bulk of gas and air, hastens the combination and hence the combustion of both.

The length of the flame proves how much time is required to complete the mixture of the combustible gas and air. Under a stationary boiler the flame has extended thirty feet from the grate. Flame, as before said, is entirely superficial, inclosing a core or central body of gas, waiting its turn to come into combination. This gas, having a progressive motion in the flues, or an ascensional power when discharged in the open air, must follow the draught, while by the continual combustion of its external atoms, its thickness is being steadily reduced, until, if not violently extinguished, it finally burns out to a point and

the flame terminates. Thus, if flame extends for thirty feet, the combining gas and air are mixing for the whole distance, and may not even be fully mixed when the flame ceases,— what remains passing off unconsumed.

The want of time is experienced with the gaseous portions of the fuel only, as these, on the moment they are distilled, are on their flight to the tubes, giving but a fraction of a second for mixture and consequent combustion in a locomotive boiler. The solid portion remains quietly on the grate and takes its own time for combustion.

It may indeed happen, as is often the case, that even where the gases and air are detained in contact for a sufficient time for mixture, other arrangements of the boiler prevent their entering into perfect combustion. The process of the combustion of the carburetted hydrogen *must* be completed *before* it reaches the tubes. If, in a locomotive boiler, the fire-box does not afford room, it must be obtained by a combustion chamber in the barrel of the boiler, and even there we must *aid* the requisite mixture by deflecting the currents of gas and air into as intimate contact as possible. We cannot control the volume of the gas after the coal is on the grate, but we can divide the air into numberless thin streams, and by means of fire-brick bridges, or plates, etc., we can *deflect* the gas into mixture with the streams of air. These arrangements apply to gaseous fuels mainly, and not to coke, nor to the same extent to anthracite coal.

It is only by supplying and mixing the full equivalent of air that the combustible elements of the coal will be so combined as to give off their full heating power, and without the production of soot and its consequent smoke.

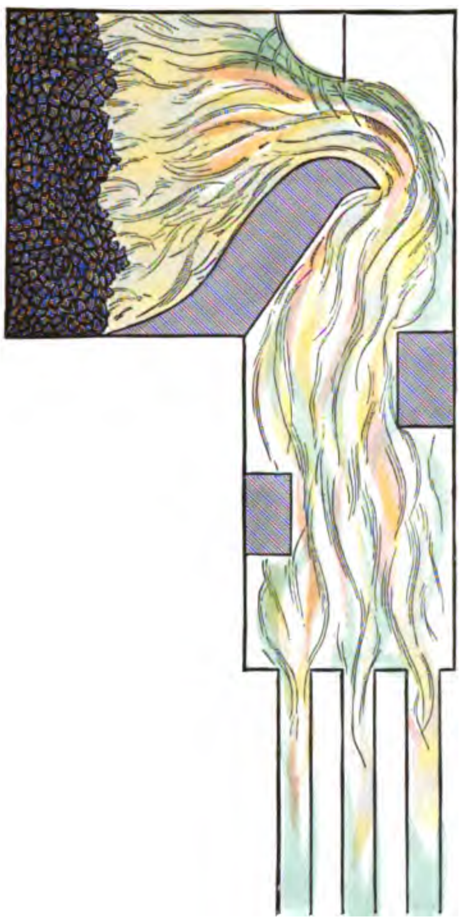


PLATE IV.

The best chemical authorities tell us that, in the most careful laboratory practice, a considerable time, often a whole day, is necessary for the complete mixture of certain gases; while those now under consideration can only mix after many minutes, and even then with an excess of oxygen, or, what is the same, an excess of air. That is, *more* air than the combining equivalent must be present in order that the combining equivalent may be taken up,—although the excess of air, above this equivalent, is not burned but passes through uncombined.

Prof. Daniell, of England, says, "Any method of insuring the complete combustion of fuel, consisting partly of the volatile hydro-carbons (compounds of carbon and hydrogen), must be founded upon the principle of producing an intimate mixture with them of atmospheric air in *excess*, in that part of the furnace to which they naturally rise."

Practically in a furnace, nearly twice the air must be present that is actually required for the combustion of the gaseous matter.

As coal, in burning, does not give off its gas uniformly and continuously, but principally soon after being thrown upon the fire, we must have such control over the admission of air as will enable us to admit the right quantity according to the variable conditions within the furnace.

In continuous flame, the successively combining atoms of gas and air are ignited by contact, the process being described as a "self-generating succession," so long as both elements are supplied. The heat under which the gas itself distills will always ignite it, if the due admixture of air is immediately obtained. If the access or mixture

of air is delayed until the gas has risen beyond the reach of an igniting temperature, it will then pass away unburned. And it is by far the more rational plan to effect the immediate admixture with air, while the gas is ready to burn, than, neglecting this mixture, to endeavor to recover lost time by *heating* the gas afterwards, when it may be supposed to have fortuitously taken up its equivalent of air.

It is evident, that to bring the coal, in both its solid and gaseous elements, into intimate mixture with air, and to ignite the compound, are all that human means can accomplish—nature only, in her own processes, effecting the rest. The distillation of gas, when fresh coal is supplied, goes on near the surface of the fire; the gas naturally burns above the surface, and the air, necessary for its combustion, must be admitted, therefore, above the surface. The necessity is this: Whatever amount of air passes through the grate will chemically combine (excepting a certain excess which must always be present), with the solid part of the coal—the coke. The product of this combustion is carbonic acid, or carbonic oxide, and, although at a great heat, the oxygen which has entered into these compounds can serve no further combustible purpose. This carbonic acid is the same as that which, settling by its weight into the bottoms of wells or pits, *extinguishes* the flame of a candle. The fumes from coke or charcoal are carbonic acid only, and are as fatal to the existence of flame as to human life. The question is often asked, "Why not provide at once for the admission, through the grate, of sufficient air both for the coke and

the gas?" This would be an impossibility, for whatever the quantity of air admitted through the grate, it will expend itself on the *coke* only,—at least until holes are burned through the fire, when the control of the air is at once lost and great waste of fuel ensues.

The admission of air above the fire must be in the greatest practicable number of small jets, since gas and air mix only gradually, excepting by division and inducement. Air, *in bulk*, mixes only superficially with gas, and, by abstracting heat, cools the furnace. The air-holes should be placed as near as practicable to where the gases rise, since, after they are disengaged from the coal, it is necessary to *commence* their combustion at the earliest moment. Gases, to be thoroughly burned in the furnace, must be intercepted by air at the *start*, else the combination, which is at best gradual, will not be *completed* in season, as what remains uncombined on reaching the *tubes* is lost.

The temperature of the air entering the furnace has been a subject of controversy. No boiler furnace, however, was ever built in which hot air was proved to increase the intensity of combustion. The idea of hot air in this case has always been traced to the *seemingly* similar application in the hot air blast furnace. There, however, the case is totally different. The iron lies among the coal, and the entering cold air *before it has combined with the carbon* chills the iron, thus rendering more coal necessary than if the iron had been heated. If, however, the air could combine with the coal *before it reached the iron*, its temperature (that of the air) would be quite a matter of

indifference. In the boiler furnace this combination takes place, or should do so, before the air reaches the plates, and the resulting heat is that generated directly within the air and coal, and cannot be derived from any outside source.

There are certain practical objections to heating air. First, for every 480° of added heat, its bulk is enlarged by the amount of its original volume; so that at 3000°, the heat of the interior of the furnace, it has six times its original volume. It is consequently more unmanageable, and as its contained oxygen retains the same weight, its mixture with the gas becomes more difficult; while when mixed it can only do the same work as before. It would be much better to condense the air than to expand it. Next, if heated by passing through flame or over burning coal, the air will be robbed of a greater or less part of its vital oxygen. This is a positive loss.

The coldest air, if thoroughly mixed on its entrance with the coal or gases, will never cool, but will always sustain or increase the heat of the furnace. Air in bulk only can do any harm, and this is objectionable from the obstruction which it forms to combustion as well as from its abstraction of heat from the furnace. Thus, it is seen, the air, divided into thin streams, should be taken from the outside of the boiler directly into the furnace.

All that now remains to be provided for are *space* and such arrangements as shall give *direction* and *time* for combustion. The great volume of gas rising from the coal cannot, even with the most ample admission and division of air, completely combine with it, except with prolonged opportunity and compulsory interfluence. By

forcing both into convolution, in a circuit of several feet, we can effect their final union without injurious obstruction to the draught.

Finally, if all the combustible elements of the coal are completely burned, no smoke can be formed, and the evaporation effected will be all of which the coal is inherently capable,— from eight to ten pounds of water for each pound of coal burned, according to its chemical constitution.

In flue or externally fired boilers the run of the gases is much longer, and thus *time* is given for a thorough admixture of air, if it be properly supplied; and in externally fired boilers, facilities exist for hanging bridges, etc., for the purpose of deflecting the gases, and thus affording a more thorough mixture of the air with them.

But it may as well be said that no matter how complete may be the arrangements of furnaces, grates, flues, bridges, etc., as well as air supply, a careless or ignorant fireman will waste coal, the waste in some cases amounting to more than thirty per cent.

To sum up, the quantity of air required for combustion varies with the composition of the fuel; but it is sufficient for practical accuracy to say that each pound of fuel requires twelve pounds of air. The volume of air, of course, will depend upon its temperature.

Now the quantity of heat which can be developed by one pound of pure carbon is sufficient to boil fifteen pounds of water from and at 212° Fahrenheit, if none of the heat were lost; but there are many reasons for non-attainment of this result in practice, and the following are some of them:

First. Differences in the chemical constituents of the coal.

Second. Impurities present in the coal.

Third. Losses by conduction and radiation in the furnaces, flues, and metal of the boiler.

Fourth. Imperfect and incomplete combustion.

Fifth. Loss of heat carried off by the chimney, partly utilized in causing the draught.

Sixth. Improper management.

There is a great difference between anthracite and bituminous coals as fuel. Anthracite burns completely with a thin fire, by admitting an excess of air through it and above it; but bituminous coal absolutely requires for its perfect combustion a high temperature and plenty of room for the products of combustion, before coming into contact with the iron of the boiler, with a proper supply of air above the fuel; and any deviation from these conditions produces smoke and loss of heat.

With hard coal, too great a draught wastes a little heat in the chimney; but with soft coal, too great a draught may be as bad in its effects as not enough. The great secret in smoke-prevention is to have a hot fire with plenty of *room* and *time* to let all the gas burn before getting lower in temperature than a red heat (800° Fahr.), and to fire in small quantities over a part of the grate at a time.

In a chimney where the draught is produced by the excess of weight of the outside air over that of the hot gas in the chimney, the greatest quantity of gas by weight will pass up the chimney when its temperature is about 625° greater than that of the outside air. But it is a well-known fact that natural draught is not so economical

as a forced draught, because a certain amount of heat is wasted in producing this draught,—about twenty-five per cent.,—and the cost of a forced draught to burn the same amount of coal in the same time is not half so great.

The power of boilers is much increased by a forced draught, the comparative efficiency being as follows:

With Natural Draught = 1
" Jet = 1.25
" Blast = 1.6

TOTAL HEAT EVOLVED BY COMBUSTIBLES, AND THEIR EQUIVALENT EVAPORATIVE POWER, WITH THE WEIGHT OF OXYGEN AND QUANTITY OF AIR CHEMICALLY CONSUMED.

COMBUSTIBLE.	*Weight of oxygen consumed per lb. of combustible.*	*Quantity of air consumed per pound of combustible.*		*Total heat of combustion of 1 lb. of combustible.*	*Equivalent evaporative power of 1 pound of combustible, under one atmosphere at 212° Fahr.*
1 lb. weight.	Lb.	Lb.	Cub. ft. at 60° Fahr.	Units.	Lbs. of water from and at 212° Fahr.
Hydrogen	8.0	34.8	457	62,032	64.2
Carbon, making Carbonic Oxide	1.33	5.8	76	4,452	4.61
Carbon, making Car. Acid	2.66	11.6	152	14,500	15.0
Carbonic Oxide	0.57	2.48	33	4,325	4.48
Light Carburetted Hydrogen	4.0	17.4	229	23,513	24.34
Bi-Carburetted Hydrogen, or Olefiant Gas	3 43	15.0	196	21,343	22.00
Sulphur	1.00	4.35	57	4,032	4.17
Coal of average Composition	2.46	10.7	140	14,133	14.62
Coke, desiccated	2.50	10.9	143	13,550	14.02
Wood	1.40	6.1	80	7,792	8.07
Peat	1.75	7.6	100	9,951	10.30
Lignite	2.03	8.85	116	11,678	12.10
Asphalt	2.73	11 87	156	16,655	17.24
Straw, 15¾ per ct. moisture	.98	4.26	56	5,196	5.56
Petroleum	4.12	17.93	235	27,531	28.50

GENERAL REMARKS ON FUEL*

IT is rarely that a manufactory does not use for its boilers nearly twice as much fuel as is necessary, if the plant was of a better type, and more skillfully managed,—and in some places the waste is greater than this.

The way in which this waste takes place may be stated generally as follows:

First. A large number of firemen do not know how to fire properly, or are careless.

Second. Many boilers are of bad design, or are improperly set.

Third. Many engines use too much steam.

Fourth. The coal used as fuel is not properly housed.

This last is, perhaps, of greater importance than steam-users generally suppose.

Experiments have shown that coal loses from ten to forty per cent. of its evaporative effect from being exposed to the effects of sunshine and rain. It should always be kept under cover, and the building should be of brick, and closed in.

It is generally conceded that two and a quarter pounds of good dry wood are equivalent in evaporative effect to one pound of good coal, but it must be remembered

PLATE V. Coal.

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that wood requires a roomier furnace than coal, and also that the spaces between the grate bars must be larger.

The fuel value of the same *weight* of different woods is very nearly the same,—that is, a pound of hickory is worth no more for fuel than a pound of pine, assuming both to be dry. If the value be measured by weight, it is important that the wood be dry, as each ten per cent. of water, or moisture, in the wood will detract about twelve per cent. from its value as a fuel.

The weight of one cord of different woods (air-dried) will be found as follows (for an honest cord of split wood):

Hickory or Hard Maple (Sugar-tree)	4500 lbs.
White Oak	3850 "
Beech, Red Oak, and Black Oak	3250 "
Poplar (white wood), Chestnut, and Elm	2350 "
The average of Pine	2000 "

The fuel value as compared with coal is about as follows:

			Lbs. of Coal.
1	cord	dried Hard Maple	2000
1	"	" White Oak	1715
1	"	" Beech, Red or Black Oak	1450
1	"	" Poplar, Chestnut, Elm	1050
1	"	" Average Pine	925

The following article on the comparative merits of anthracite and bituminous coals was taken from the *American Engineer.*

A board of officers was appointed by the Navy Department "to investigate the comparative merits of anthracite

and bituminous coals for ordinary naval uses," etc., and their report has been lately issued. The question is considered as follows:

HEATING POWER.—The Navy Department was originally induced to employ anthracite, chiefly on account of the report of Prof. Johnson, in 1844, that the evaporative efficiency of average anthracite was greater than that of bituminous coal—9.56 pounds of water being evaporated per pound of anthracite, and 8.94 per pound of bituminous coal. They did not fully include the very important circumstances that anthracite fires need to be cleaned in longer service than about twelve hours, and after that time should be more or less thoroughly cleaned once in every twelve hours. This causes loss of evaporative power in the following ways, to which the free-burning coals are subject in much less degree:

(a) By the direct abstraction of heat from the combustible portion of the fuel to bring the earthy matter and ash to the high furnace temperature; *(b)* By the direct loss of heat when the clinkers and ashes are withdrawn at that high temperature; *(c)* By the unavoidable loss of some unconsumed coal during the abstraction of the clinkers; *(d)* By the influx of cold air through the open furnace-door during the operation of cleaning fires; *(e)* By the loss of heat expended in raising the temperature of air over and above the quantity needed for combustion; *(f)* By the loss of effect during the time that fire newly cleaned requires to recover full action.

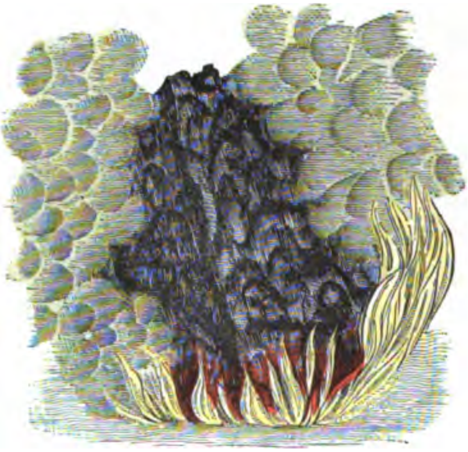


PLATE VI. First Stage — Distilling Gas.

The average evaporative power of the semi-bituminous coal is higher than the average evaporative power of the anthracites, being 9.9804 and 9.5648 pounds of water from 212° Fahr., respectively. Their conclusion is strengthened by results of Isherwood's experiments with several marine boilers, in which Cumberland semi-bituminous coal generally evaporated more water than Pennsylvania and other anthracites. And these results are further corroborated by experiments of the Baltimore and Ohio Railroad, in which the evaporative effect of one ton of Cumberland coal was found to equal that of one and one-quarter tons of anthracite.

It is asserted that when combustion is forced, the economic evaporation is relatively less with free-burning coal than with anthracite; but it may be answered that under circumstances in which the blast or steam jet is used, economy is temporarily ignored, the object being to produce active combustion regardless of cost.

Promptness of Ignition.—On this point the report shows that this quality is so valuable in a naval vessel that it almost precludes the employment of anthracite in time of war in favor of more free-burning coal, and that it has considerable advantages in time of peace.

Weight of a Given Bulk.—The report says that the average of all the semi-bituminous coals of Maryland gives rather the smallest space occupied per ton (42.0372 cubic feet), the anthracite ranking second (42.13 cubic feet), the bituminous coals of Pennsylvania being third, but with very trifling difference (42.671 cubic feet), the

coking coals of Virginia being the only free-burning varieties which are decidedly lighter (45.8804 cubic feet), indicating that anthracite is the heaviest class of coal.

SMOKE AND SOOT.—In non-production of smoke, anthracite takes the lead; also in freedom from soot.

ACTION UPON BOILERS, GRATES, ETC.—In this respect the report says it is likely there is not much to choose between the anthracites and free-burning coals, at least with iron boilers; for, whereas the intense local heat of an anthracite fire searches and develops any tendency toward blistering or lamination in boiler iron, there are several varieties of free-burning coal which contain sulphur, and which are injurious on that account to tube ends, etc. Both classes will, under certain circumstances, warp and destroy grate bars.

IMPURITIES.—This subject has been covered in a former division of the report. If spontaneous combustion is feared, the coal should be free from pyrites.

DETERIORATION.—It is probably true that anthracite will scarcely deteriorate in heat-giving power except after long exposure to the direct action of the sun. The free-burning coals, on the other hand, rapidly lose their cohesion and heat-giving power. Anthracite, under favorable circumstances, would last almost indefinitely.

FRIABILITY.—The slack of anthracite is worthless on the grates of a boiler, whereas a free-burning coal, if not too old, is tolerably efficient in the formation of steam.

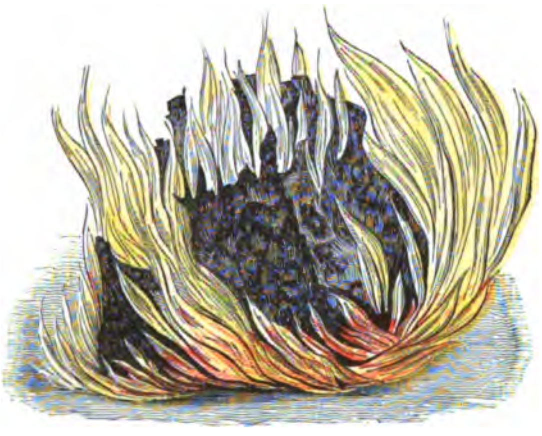


PLATE VII. Second Stage — Burning Gas.

SPONTANEOUS COMBUSTION.— In this respect, anthracite exceeds all other coals, being entirely free from this source of danger.

COMPLETENESS OF COMBUSTION.— This is a quality possessed to a greater degree in most of the semi-bituminous coals than in most of the anthracites. Besides the wastefulness caused in the furnace by the greater average formation of clinker with the latter coal, there is the greater labor necessary and time lost in their removal from the boiler and their being disposed of.

Fuel is often wasted from the bars not being properly spaced, and the following table may prove of service:

SPACE BETWEEN GRATE BARS.

Lehigh Anthracite, pea coal	¼ of an inch.
Schuylkill " "	⅜ " "
Lehigh " chestnut coal	⅜ " "
Lehigh " stove "	½ " "
Lehigh " broken "	⅝ " "
Cumberland Bituminous Coal	¾ " "
Wood	¾ to 1 " "
Sawdust	$\frac{3}{16}$ to ¼ " "

NOTE.— In estimating for a consumption of 14 lbs. of coal per square foot of grate per hour, about 8 lbs. of water may be taken as the rate of evaporation per 1 lb. of coal, which can be done with a good natural draught. With a forced draught and 28 lbs. of coal to the square foot of grate, the rate of evaporation is only about 6 lbs. of water to 1 lb. of coal.

TABLE SHOWING THE VALUE AND PROPERTIES OF VARIOUS KINDS OF COAL.

DESIGNATION OF COAL.	*Weight per cubic foot by experiment.*	*Cubic feet of space required to stow 1 ton.*	*Volatile combustible matter in 100 parts.*	*Fixed carbon in 100 parts.*	*Earthy matter in 100 parts.*	*Pounds of steam to 1 of coal from 212°.*	*Total waste (ashes and clinker) from 100 of coal.*	*Weight of clinker alone from 100 of coal.*	*Av. weight in pounds of unburnt coke left on grate after such experiment.*	*Steam from 212° from 1 of combustible matter.*
Beaver Meadow, slope No. 3 ...... Pa..	54.93	40.78	2.38	88.94	7.11	9.21	11.96	1.01	112.4	10,462
Beaver Meadow, slope No. 5 ...... Pa..	56.19	39.86	2.66	91.47	5.15	9.88	6.74	0.60	61.2	10,592
Forest Improvement .... Pa..	53.66	41.75	3.07	90.75	4.41	10.06	6.97	0.81	40.2	10,807
Peach Mountain .... Pa..	53.79	41.64	2.96	89.02	6.13	10.11	6.97	3.03	26.6	10,871
Lehigh .... Pa..	55.32	40.50	5.28	89.15	5.56	8.93	7.22	1.08	36.1	9,626
Lackawanna .... Pa..	48.89	45.82	3.91	87.74	6.35	9.79	8.93	1.24	57.2	10,764
Lyken's Valley .... Pa..	48.56	46.13	6.88	83.84	9.25	9.46	12.24	4.40	18.0	10,788
Beaver Meadow (Navy Yard) .... Pa.	55.08	40.65	....	....	8.10	9.08	8.10	1.40	107.1	9,881
Natural Coke of Virginia .... Va..	46.64	48.03	12.44	75.08	11.83	8.47	18.46	5.31	60.9	10,389
Coke of Midlothian Coal .... Va..	32.70	68.50	....	....	16.55	8.63	16.54	10.51	53.2	10,343
Coke of Neff's (Cumberland) Coal . Md..	31.57	70.95	....	....	13.34	9.00	13.34	3.55	43.7	10,381
Mixture 1-5 Cumb. and 4-5 Beaver Meadow	54.29	41.26	....	....	8.88	8.86	8.88	4.91	9.5	9,725
Mixture 1-5 Cumb. and 4-5 Beaver Meadow	54.51	41.09	....	....	8.18	9.18	8.18	3.09	16.0	9,997
N. Y. and Maryland Mining Co. .. Md..	53.70	41.71	12.31	73.50	12.40	9.78	12.71	5.43	10.1	11,208
Neff's Cumberland .... Md..	54.29	41.26	12.67	74.53	10.34	9.44	10.96	4.53	6.1	10,604
Easby's "coal in store" .... Md..	53.47	41.90	14.98	76.26	8.08	10.02	8.38	1.33	18.2	10,935
Atkinson and Templeman's .... Md..	52.92	42.33	15.53	76.69	7.33	10.70	7.96	2.12	5.1	11,624
Easby and Smith's .... Md..	51.16	43.78	15.52	74.29	9.30	9.96	9.69	3.04	5.8	11,084
Cumberland (Navy Yard) .... Md..	53.29	42.04	14.87	70.85	14.98	....	14.53	2.29	13.5	......
Dauphin and Susquehanna .... Pa..	50.54	44.32	13.82	74.24	11.49	9.34	16.36	3.50	23.7	11,171
Blossburgh .... Pa..	53.05	42.22	14.78	73.11	10.77	9.72	11.20	3.40	13.7	10,956
Lycoming Creek .... Pa..	55.38	40.45	13.84	71.53	13.96	8.91	16.92	3.26	46.2	10,724

TABLE SHOWING THE VALUE AND PROPERTIES OF VARIOUS KINDS OF COAL.—*Continued.*

DESIGNATION OF COAL.	*Weight per cubic foot by experiment.*	*Cubic feet of space required to stow 1 ton.*	*Volatile combustible matter in 100 parts.*	*Fixed carbon in 100 parts.*	*Earthy matter in 100 parts.*	*Pounds of steam to 1 of coal from 212°.*	*Total waste (ashes and clinker) from 100 of coal.*	*Weight of clinker alone from 100 of coal.*	*Av. weight in pounds of unburnt coke left on grate after such experiment.*	*Steam from 212° from 1 of combustible matter.*
Quin's Run .... Pa..	50.34	44.50	17.97	72.79	8.41	10.27	8.94	1.31	14.7	11,275
Karthaus .... Pa..	52.54	42.63	19.53	73.77	7.00	9.09	7.89	3.66	52.5	9,887
Cumbria County .... Pa..	53.46	41.90	20.52	69.37	9.15	9.24	9.75	3.48	14.8	10,239
Barr's Deep Run .... Va..	53.17	42.13	19.78	67.96	10.47	9.02	11.07	4.78	6.4	10,142
Crouch and Snead's .... Va..	53.59	41.80	24.38	59.98	14.28	8.34	14.34	5.37	6.0	9,740
Midlothian (900-foot shaft) .... Va..	50.52	44.34	27.28	61.08	10.47	8.58	10.70	6.47	5.9	9,611
Creek Company's Coal .... Va..	46.50	48.17	32.47	60.30	8.57	8.42	8.64	4.41	10.5	9,211
Clover Hill .... Va..	45.49	49.25	32.21	56.83	10.13	7.67	10.60	3.86	11.5	8,588
Chesterfield Mining Co's .... Va..	45.55	49.18	32.63	58.79	8.63	9.00	9.07	4.19	10.5	9,896
Midlothian (average) .... Va..	54.04	41.45	29.86	53.01	14.74	8.29	14.83	8.82	6.4	9,741
Tippecanoe .... Va..	45.10	49.67	34.54	54.62	9.37	7.75	9.72	4.03	11.2	8,583
Midlothian (new shaft) .... Va..	47.90	46.76	35.77	56.40	9.44	8.75	10.26	4.21	17.1	9,751
Midlothian (screened) .... Va..	45.72	48.99	34.70	54.06	9.66	8.94	10.27	3.33	14.8	9,970
Midlothian (Navy Yard) .... Va..	54.47	41.13	29.12	56.11	14.14	....	....	4.42	43.2	......
Pictou (from New-York) .... N. S..	53.55	41.83	27.83	56.98	13.39	8.41	13.37	6.13	5.7	9,710
Sidney .... N. S..	47.44	47.22	23.81	67.57	5.49	7.99	6.01	2.24	5.9	8,497
Pictou (Cunard's) .... N. S..	49.25	45.48	25.97	60.74	12.51	8.48	12.06	6.19	3.7	9,648
Liverpool .... Eng..	47.88	46.78	39.96	54.90	4.62	7.48	5.04	1.86	11.1	8,255
Newcastle .... Eng..	50.82	44.08	35.83	57.00	5.40	8.66	5.68	3.14	10.7	9,178
Scotch .... Scotland..	51.09	43.84	39.19	48.81	9.34	6.95	10.10	5.63	5.7	7,719
Pittsburgh .... Pa..	46.81	47.85	36.76	54.93	7.07	8.20	8.25	0.94	9.9	8,942
Cannelton .... Ind..	47.65	47.01	33.99	58.44	4.97	7.34	5.12	1.64	6.4	7,734
Dry Pinewood	21.01	106.02	....	....	0.30	4.69	0.30	....	....	4,707

TABLE OF RESULTS OF

TESTS OF COAL—MADE JUNE TO OCTOBER, 1883.*

NAME OF COAL.	BY WHOM FURNISHED.	Average water evaporation per pound of coal feed water 212° Fahr.	Taking Grape Creek, Illinois, as the basis of comparison at 100, other coal would stand in comparison at
Grape Creek, Illinois	Grape Creek Coal Co	7.19	100
Wilmington & Springfield, Illinois		7.34	102
Streator, Illinois	Arnold & Co	7.55	105
Streator, Illinois	Chicago, Wilmington & V. Coal Co	7.63	106
Wilmington, Illinois		7.88	109
Indiana Block	E. T. Ellicott	7.87	109
Indiana Block	C. B. Niblock	8.12	113
Gartsherrie, Indiana Block	Watson & Co	8.52	118
"Kincaid," Hocking Valley	Baker & Co	8.48	117
B. & O. Hocking Valley	Moody & Co	8.20	114
Briar Ridge, Hocking Valley	Shipman	8.60	119
Shawnee, Hocking Valley	Dewey & Co	8.62	119
Briar Ridge, Hocking Valley (2d test)	Shipman	8.71	121
Laurel Hill, Pittsburgh	W. P. Rend & Co	12.92	179

TESTS OF COAL—MADE APRIL, MAY, AND JUNE, 1885.

Hocking Valley	W. C. Wyman	8.34	116
Jacksonville, Hocking Valley	W. P. Rend & Co	8.78	122
Youghiogheny, Pittsburgh	Weaver, Daniels & Co	10.40	144
Youghiogheny, Pittsburgh (2d test)	Weaver, Daniels & Co	12.24	170
Osceola, Pittsburgh	Costello & Co	12.36	172
Laurel Hill, Pittsburgh	W. P. Rend & Co	13.14	182

* Experiments made by the Chief Engineer and Commissioner of Public Works of the City of Chicago, as published in the *American Engineer*.

Plate VIII. Coke.

INCRUSTATION

WATER is rarely found pure, *i. e.*, not holding foreign substances in solution. Consequently, if water is poured into a vessel placed over a fire, it boils, and escapes as steam; but, on examining the vessel, we shall find on the bottom and sides a coating, either *hard*, in which case it is called incrustation or scale, or else, the deposit is in the form of an impalpable powder, and is then called sediment. Sometimes, also, water holds mineral substances in mechanical suspension.

Again, fatty matters in the feed water of a boiler cause a deposit also, forming a firmly adhering incrustation.

The substances more generally in solution in water are the carbonates of lime and magnesia, sulphate of lime, chloride of magnesia — with traces of silica alumina, and iron.

In sea-water, chloride of sodium is the principal foreign matter present, though the carbonates of lime and magnesia, and sulphate of lime, are also found, and are the principal constituents of the scale formed.

The deposit formed in a boiler by the evaporation of the water which held it in solution, whether it is in the form of scale or is simply a fine powder, is a source of waste, and is oftentimes expensive to remove.

Water holding substances in mechanical suspension merely can be easily filtered, but to remove those substances chemically combined with it is often a difficult and expensive affair.

Heat is the only agent by which all the matter held in solution can be removed from the water.

The amount of mineral matter held in solution by water, as found in rivers, streams, and lakes, varies from ten to forty grains per gallon of two hundred and thirty-one cubic inches; well and mine waters contain more.

As water contains all the incrustating ingredients found in boilers, having been the means of conveying them there, it will be well to speak of the composition and properties of water.

Water is composed of two gases, hydrogen and oxygen, in proportion, by weight, of 11.1 parts of hydrogen and 88.9 parts of oxygen, or, in chemical combination, of two atoms of hydrogen and one of oxygen.

Water, when pure, and in small quantities, is transparent, colorless, tasteless, odorless, and is a bad conductor of heat and electricity. Under a pressure of 30,000 lbs. to the square inch fourteen volumes may be condensed into thirteen volumes, so that it is slighty elastic. It is eight hundred and fifteen times heavier than atmospheric air, an imperial gallon (277.274 cubic inches) weighing at 62° Fahr. and a barometric pressure of 29.92 inches 70,000 grains, or ten pounds avoirdupois; but, as it is the standard to which the gravities of solids and fluids are referred, its specific weight is called 1.0.

Water contracts and becomes denser in cooling, until it reaches 39°.2 Fahr., when it has reached its greatest

density. Below this point it expands, and at 32° Fahr. it becomes solid, or freezes, and in the act of freezing expands considerably. Owing to the expansion ice is lighter than water, having a specific gravity of 0.916. The bursting of water pipes is often due to the expansion of the water in them while freezing.

Water expands by the application of heat between 40° Fahr. and 212° Fahr., boiling at the latter temperature in metallic vessels when the barometric pressure is 29.92 inches.

On the first application of heat to water small bubbles soon begin to form and rise to the surface; these consist of air, which all water contains dissolved in it. When it reaches the boiling point the bubbles that rise in it are principally steam.

The boiling point of water varies according to the pressure. As before mentioned, with a pressure of 29.92 inches it boils at 212° Fahr.; at a pressure of 27.74 inches it boils at 208° Fahr.

This change of temperature is used to ascertain the height of mountains—550 feet making a difference of 1°. In a vacuum water will boil at 67° Fahr.

The solvent properties of water far exceed those of any other known liquid. A very large proportion of the different salts are more or less soluble in it, the solubility increasing generally as the temperature rises, so that a hot saturated solution deposits crystals on cooling.

There are a few exceptions to this rule, one of which is common salt, the solubility of which is nearly the same at all temperatures, the hydrate of lime (slaked lime) being more soluble in cold than in hot water, sulphate of lime

being also less soluble in hot than in cold water, and insoluble at 302° Fahr., or between 284° and 302° Fahr. It also dissolves gases, but a boiling temperature expels all the gas if it be not very soluble. The solvent properties of water are still further increased when heated in a strong vessel under pressure.

RIVER WATER containing carbonate of lime, held in solution by the presence of free carbonic acid, boils steadily and is not liable to cause foaming. As the water boils the carbonic acid gradually escapes, the carbonate of lime at the same time being deposited in the insoluble state, and, in many instances, in the crystalline state. The slower it is deposited the more crystalline it will be. Sometimes it becomes hard as rock and has to be chipped off.

This incrustation also contains some sulphate of lime, the sulphate of lime being less soluble in hot than in cold water, as before mentioned. This incrustation gradually eats away a portion of the metal, to which it becomes so tightly fastened that when it is chipped off there will always be found a layer of oxide of iron on that side of the incrustation which was in contact with the metal. Incrustation is commonly stated to be a bad conductor of heat, and that any great thickness of it on the plates causes a largely increased expenditure of fuel. It is not clearly determined yet whether the increased expenditure of fuel is quite so great as has been claimed—though it is undoubtedly a source of waste.

As the water boils, and the steam is used, more water is continually added to the boiler to supply the place of that

converted into steam. The carbonate and sulphate of lime being deposited during the process of boiling, the proportion of these in the water of the boiler does not increase to any extent; but such is not the case with the chloride of sodium (common salt). This being so very soluble remains in solution, and is, of course, gradually increasing in the water of the boiler until it is strong enough to set up a galvanic action between the metals where brass or copper comes in contact with the iron, as cocks, etc. The iron is the metal attacked, and, being gradually eaten away around the brass or copper, gives rise to leaks; the incrustation of carbonate and sulphate of lime having the same effect, only in a less degree.

Those wells which yield hard water act upon boilers in exactly the same manner as river water; but from the fact of their containing more solid matter per gallon, an equal quantity of these waters would yield a larger incrustation than river water.

Well water containing a quantity of soluble salts acts upon the brass and copper to such an extent that boilers are almost covered in front with incrustations of salt; the boilers of course are greatly injured, and rapidly destroyed.

SEA WATER acts in the same way on iron boilers, but being a stronger solution it requires no concentration before it begins to take effect, and must be frequently blown off.

Zinc has proved to be one of the most effectual materials for preventing corrosion in marine boilers. It is usually applied by fixing slabs of zinc in various positions in the

boiler, exposing about one square foot of surface for every twenty indicated horse-power.

These slabs in a comparatively short time are found to be in a state of oxide and crumbling away. The whole is then renewed, and will last for a longer period when it is once renewed.

Dr. Gideon E. Moore, of New-York City, analyzed some specimens of zinc taken from the boilers of the steamer "Rosedale," plying between the cities of New-York and Bridgeport, using a mixture of salt and fresh water, and the following results were obtained:

Moisture	1.32
Oxide of Zinc	95.23
Sesquioxide of Iron	0.96
Lime	0.23
Magnesia	0.95
Oxide of Lead	1.16
Chlorine	0.18
Sand and Insoluble Matter	0.37
	100.40

A small portion of the zinc was present in the metallic state and was the cause of the dark color of the sample.

The changes produced in the composition of the spelter by the action of the water in the boiler have, as shown by the foregoing analysis, been restricted chiefly to the transformation of the metal into oxide. The destruction of the boiler by oxidation has thus been retarded.

The most important effect from using zinc in marine boilers is, however, the protection of the latter from the

hydrochloric acid evolved from the chloride of magnesium of the sea water. This, however, would leave little trace on the zinc residuum, except the presence of a little magnesia, as shown in the analysis.

Dr. Kossman states that zinc introduced into steam boilers to prevent incrustation proves very useful in case of selenitic waters, but as against the carbonate of lime, magnesia, and iron, it is of little value, the zinc being soon rendered brittle and porous, and in a short time reduced to powder.

There are a large number of compounds for preventing incrustation, but the majority are very costly, and the benefit derived from them is not usually equal to the outlay; and it takes quite as much time to clean the boilers out when compositions are used as otherwise. Some compounds increase corrosion while they prevent incrustation, and in the use of others practical difficulties arise which render their use inconvenient and dangerous.

There are also many compounds for loosening and facilitating the removal of incrustation after it has formed; but there is probably no compound that will, with all waters, entirely prevent its formation. It is well known, however, that a number of compositions that have been complete failures with some waters have yielded much better results with others. There can be no question that river, well, and spring waters greatly vary in different localities, and the remedy cannot, therefore, be constant.

If boiler compositions are used at all, care must be taken that they do not affect the metal of the boilers, and

they must also meet the impurities and chemical properties of the water to which they are applied.

In the following tables are shown the varying amounts of mineral and organic matter held in solution by the waters of different localities.

ANALYSIS OF WATER BY PROF. C. F. CHANDLER, COLUMBIA COLLEGE.

TABLE SHOWING WEIGHT OF IMPURITIES, IN GRAINS, IN 1 U. S. GALLON, 231 CUBIC INCHES.

No.	*Source.*	*Corroding matter.*	*Incrusting matter.*	*Organic matter.*	*Total solids.*
1	Syracuse, Onondaga Creek....	3.44	22.58	0.34	26.36
2	" hydrant.	0.38	27.55	trace.	27.93
3	Memphis........................	0.91	21.68	0.18	22.77
4	Jordan..........................	1.71	11.47	0.06	13.24
5	Port Byron....................	1.08	7.17	1.28	9.53
6	Savannah	1.35	17.63	1.52	20.50
7	Clyde, spring..................	0.77	14.64	2.16	17.58
8	" river	2.10	14.30	1.88	18.28
9	Lyons..........................	1.03	11.07	1.00	13.10
10	Newark........................	1.17	18.73	2.16	22.07
11	Palmyra	1.43	33.39	1.46	36.28
12	Macedon Swamp.............	0.71	10.53	0 80	12.04
13	Fairport	3.19	15.06	1.14	19.39
14	Rochester, North Street well..	7.31	33.26	1.60	42.17
15	" Genesee River.....	1.18	10.85	1.64	13.67
16	" Canal, round-house	1.11	8.80	1.24	11.15
	Incrustation preventives.				
17	Warner's 8.26	3.72	11.28	0.37	23.63

These places are on the line of the New York Central R. R.

The corroding matters are, the chlorides of potassium, sodium, and manganese, and the sulphates of potassa and

soda. The incrusting matters are the sulphate of lime, the carbonates of lime and magnesia, the oxide of iron, and silica. The incrustation preventives are the carbonates of soda and potassa.

Six specimens of incrustation analyzed by Prof. Chandler gave as an average composition:

Sulphate of Lime	56.49
Carbonate of Lime	18.11
Basic Carbonate of Magnesia	19.77
Oxide of Iron and Alumina	0.69
Silica	3.81
Organic Matter	undetermined
Water	1.62
	100.00

These analyses show that the incrustations consisted chiefly of the carbonates of lime and magnesia, and the sulphate of lime.

The two carbonates are insoluble in pure water, and owe their presence in the waters of springs and rivers to free carbonic acid, which forms with them soluble bicarbonates.

Boiling such waters expels this carbonic acid, and the carbonates of lime and magnesia separate in the form of insoluble powders. Now if this boiling takes place, for the purpose of generating steam, in an ordinary boiler, these carbonates are set free as impalpable powder and buoyed to the surface of the water, where they remain for some time, gradually being carried to the comparatively cooler and quieter parts of the boiler, where they quietly

and gradually settle, forming sludge. Were some suitable means provided they could be collected at the surface, and blown out at intervals, without much loss of efficiency in the boiler, the ordinary means of a common surface blow being very wasteful, as generally applied.

Various alkaline substances, by appropriating the carbonic acid, cause the precipitation of the insoluble carbonates.

Potash, soda, and ammonia, as well as their carbonates, produce this effect. So that the carbonates may be removed without decomposition by simply depriving them of their solvent, the carbonic acid, and this can be done in tanks, and the purified water fed into the boiler; but the process requires care.

The sulphate of lime is soluble in water, one gallon of water being capable of holding one hundred and fifty grains in solution, but the solubility of the sulphate of lime in water is modified by the presence of other substances. The chlorides of calcium and magnesium, and even a high temperature, diminish, while the chlorides of sodium and ammonium, and various organic substances, increase its solubility. Above 212° Fahr. the solubility rapidly diminishes as the temperature increases, and at 302° Fahr., equivalent to a pressure of seventy pounds, it may be said to be totally insoluble, and, in fact at a temperature of 250° Fahr., equivalent to a pressure of thirty pounds, so much of the sulphate of lime is rendered insoluble that the quantity remaining in solution is not practically objectionable.

Sulphate of lime forms a hard crystalline scale in the absence of carbonates. When the carbonates of lime and magnesia are present the deposits vary from a loose powder to a hard crystalline formation, according to the relative proportions of the three substances.

In practice sulphate of lime can only be removed from water by undergoing decomposition; for instance, by carbonate of soda, which forms carbonate of lime, which is deposited as a powder, and sulphate of soda, which remains in solution. But when soda is used it is advisable to have some surface-blow apparatus fitted to the boiler, to avoid trouble from "foaming."

Incrustations are injurious to boilers because—

1st. They are poor conductors of heat—and so cause great loss of heat supplied to the water, and as a consequence waste of fuel. This waste is estimated from fifteen up to forty per cent. of the fuel used, dependent upon the thickness of the scale.

2nd. They cause an overheating of the boiler plates, which is sure, sooner or later, to cause a burning out of the metal, which may result in an explosion of the boiler.

3rd. The corrosion of the metal occurs most rapidly in those parts of the boiler upon which the deposits are more liable to accumulate.

The table following shows the amount of foreign matter held in solution in the waters of different parts of the New England States:

ANALYSIS OF WATER BY S. DANA HAYES.

TABLE SHOWING WEIGHT OF IMPURITIES, IN GRAINS, IN ONE U. S. GALLON, 231 CUBIC INCHES.

No.	Source.	Mineral matter.	Organic matter.	Total Solids.
	MAINE.			
1	Pure spring, near Auburn	0.85	0.13	0.98
2	Spring on Cape Elizabeth	7.40	2.21	9.61
3	Wells in Portland (average of four)	13.35	5.13	18.48
	NEW HAMPSHIRE.			
4	Merrimac River at Manchester (drainage)	2.96	2.60	5.56
5	Merrimac River at Lowell, Mass	1.80	0.11	1.91
6	Massabeesic Lake, near Manchester	1.16	1.66	2.82
7	Hotel well, on Rye Beach	6.08	2.43	8.51
	VERMONT.			
8	Mineral Springs, near St. Albans (average of seven)	15.24	1.25	16.49
9	Mineral Springs, at Guilford (chalybeate)	25.27	1.65	26.92
10	" " at Brunswick	77.79	2.33	80.12
11	" " at Danby	7.19	0.91	8.10
	MASSACHUSETTS.			
12	Cochituate, Boston, Feb., 1871	2.37	0.83	3.20
13	Mystic, Charlestown, Feb., 1871	3.96	1.72	5.68
14	Jamaica Pond, Roxbury, 1867	2.41	1.36	3.77
15	Connecticut River, at Holyoke	1.81	1.39	3.20
16	Saugus River, Lynn	3.12	2.40	5.52
17	Flax Pond, Lynn (drainage)	2.24	1.84	4.08
18	Horn Pond, Woburn	3.85	1.59	5.44
19	Locomotive supply, Taunton	4.37	2.03	6.40
20	Artesian well, Dedham	4.08	1.11	5.19
21	Wells in Woburn (average of four)	51.52	4.60	56.12
22	Wells in Lynn (average of six)	19.27	4.23	23.50
23	Old Artesian well, Boston (reopened 1871)	54.35	1.85	56.20
24	Well on Cape Cod	10.01	2.41	12.42
25	Brewery Spring, Boston	13.68	1.68	15.36

The components of the solid matters held in solution in fresh water, as shown in the tables, vary greatly in proportion and kind, but in sea-water the proportions are sensibly constant.

Annexed is an analysis of sea-water:

COMPOSITION OF SOLID MATTER, IN GRAINS, IN 1000 PARTS OF WATER.

	English Channel.		*Mediterranean.*
Chloride of Sodium	27.064	..	27.220
Chloride of Potassium	0.765	..	0.010
Chloride of Magnesium	3.666	..	6.140
Bromide of Magnesium	0.029	..	.....
Sulphate of Magnesia	2.296	..	7.020
Sulphate of Lime	1.406	..	0.150
Carbonate of Lime	0.033	..	0.200
	35.255	..	40.740

Ordinary sea-water may be considered to contain, on the average, about 3.5 per cent. of saline matter, or about 250 grains to the gallon, and is on this account unfit to drink.

So far incrustations due to the deposition of matter held in solution in the water only have been spoken of, as those are by far the most frequent. But it is known that a quantity of fatty matter in the feed water of a boiler causes a deposit which is not wet by water, and that this may lead to the destruction of the boiler, inasmuch as the part of the boiler shell under the incrustation becomes more heated than other parts, and is apt to occasion rup-

ture. A case of this kind, observed by M. Birnbaum is as follows: The boiler had become leaky about two months after working had commenced, and most likely from a cause like that indicated, the incrusted boiler plates getting heated, and being bellied out by the steam pressure; when the boiler cooled, the metal sought to right itself, and thereby a force was developed sufficient to tear the rivet holes.

In the boiler there was formed, besides a paper-thick coating of the usual deposit over the whole surface that was under water, a layer (from $\frac{5}{64}''$ to $\frac{1}{8}''$ thick) of pulverulent matter, on the fire sheets of the boiler bottom, which was a little inclined towards the furnace. This powder was found very difficult to wet with water. Analysis showed that the incrustation contained a soap not soluble in water; that there was at least six per cent. fatty acid present in the form of an insoluble soap. This fatty acid must have been neutralized by a certain quantity of lime or magnesia, and this fact was afterward determined by a quantitative analysis. The evil came from the exhaust steam of the engine from an open heater, from which the boiler feed was taken.

Several cases have come under the notice of the United States Steamboat Inspectors where oil, used to lubricate the cylinders, has been carried into the boilers with the feed water, and settling upon the furnace crowns has formed a hard incrustation there, which resulted in burning the plates, followed by a crack, necessitating repairs.

Below is given an analysis of the water in Syracuse, N. Y., taken from five different localities:

AMOUNT OF IMPURITIES, IN GRAINS, IN ONE UNITED STATES GALLON, 231 CUBIC INCHES.

Locality.	*Organic matter.*	*Calcium sulphate.*	*Calcium carbonate.*	*Magnesium sulphate.*	*Magnesium carbonate.*	*Aluminum silicate.*	*Iron.*	*Silica.*	*Sodium chloride.*	*Total Solids.*
1	0.17	5.67	9.12	3.07	4.32	3.03	0.08	0.28	1.28	27.02
2	0.18	3.94	10.01	3.05	4.32	3.00	0.08	0.24	1.27	26.11
3	0.23	4.82	9.19	3.06	4.34	3.00	0.09	0.25	1.27	26.25
4	0.16	4.85	10.12	2.05	4.32	3.89	0.08	0.28	1.28	27.03
5	0.18	4.69	8.92	2.08	4.32	3.80	0.12	0.26	1.27	25.62
Average.	0.184	4.794	9.490	3.062	4.324	2.944	0.090	0.262	1.274	26.406

There is no doubt that the use of apparatus for collecting the fine particles of the minerals, as they are freed from solution by heat, pressure, and chemical reactions in the boiler, while they are still near the surface of the water, and then periodically blowing them out, will certainly greatly reduce the amount of incrustation, and thus add to the efficiency and life of the boiler.

The wasteful effects of incrustation are shown by the following extract from the report of the performance of a boiler in the Conservatory, France:

	Water vaporized per hour.	*Coal burned per hour.*	*Steam per kilo of coal per hour.*
Boiler clean.......	200 litres	25.5 kilos	8.50
Boiler incrusted....	136 litres	34.7 kilos	3.87

Thus after incrustation for a long time, the useful effect of the coal is reduced to fifty-six per cent. of what it was when the boiler was clean.

Incrustation, or scale, as it is generally called, is a bad conductor of heat; still, a slight coating of scale, less than one-sixteenth of an inch, is sometimes needed to prevent corrosion. It is a source of danger, as it clogs the feed and blow-pipes, and also the water-legs, and by allowing the plates to become over-heated, causes burns and consequent cracks, which may result in an explosion. And, again, if a boiler is much incrusted, it is impossible to examine it so thoroughly as to ascertain the true condition of the plates, joints, rivets, braces, etc. This incrustation must be removed, and the very cleaning of a boiler tends to injure the plates and weaken the structure, when hammers and chisels are used, which is most frequently the case.

In the alkali regions of the United States it is very hard to keep boilers in a passable condition, as the water is strongly impregnated with mineral substances. Accounts are given of the use of kerosene oil for the purpose of removing scale, and apparently with success. But it is an article that must be used with great care and judgment, or the boiler will be soon ruined. Again, as before mentioned, much of the deposit in a boiler lies in the bottom as a sludge, and should be removed from the boiler as such. But when fires are hauled at the end of a week's work, steam blown off, and the water blown out of the boiler, on examining the boiler, within twenty-four hours, it will be found that the heat of the iron and brick work has baked that sludge into a hard scale, very difficult to remove.

In view of what has been shown in regard to incrustation, the following is strongly recommended:

1. The use of the purest waters that can be obtained.
2. Frequent use of a surface as well as a bottom blow-cock.
3. That the boilers never be emptied until they are so cool that the deposits will not bake on the metal.
4. Frequent washings-out.

So far, mention has been made only of internal incrustations due to foreign matter held in solution by the feed-water; but there are also deposits, forming incrustations, in the flues and tubes. Professor Hayes, in speaking of the deposits in flues and tubes, says:

"They are of two kinds, both of which are capable of corroding the iron rapidly, especially when the boilers are heated and in operation. The most common one consists of soot (nearly pure carbon) saturated with pyroligneous acid, and contains a large proportion of iron if the deposit is an old one, or very little if it has been recently formed. The other has a basis of soot and fine coal-ashes (silicate of alumina), filled with sulphur acids, and containing more or less iron, the quantity depending on the age of the deposit. The pyroligneous deposits are always occasioned by want of judgment in kindling and managing the fires. The boilers being cold, the fires are generally started with wood; pyroligneous acid then distils over into the tubes, and, collecting with the soot already there from the first kindling fires, forms the nucleus for the deposits, which soon become permanent and more dangerous every time wood is used in the furnace afterwards.

"The sulphur-acid deposits derive their acids from the coal used, but the basis material, holding these acids, is at first occasioned by cleaning or shaking the grates soon after adding fresh charges of

coal. Fine ashes are thus driven into the flues at the opportune moment for them to become absorbents for the sulphur compounds distilling from the coals, and the corrosion of the iron follows rapidly after the formation of these deposits."

It is well to remark that the afore-mentioned deposits form a very hard incrustation, though of but little thickness generally, and that they are very bad conductors of heat; therefore, their removal is a necessity.

CORROSION

A BOILER from the time it is first set to work is constantly acted upon by forces, tending to destroy it, which are varying in strength and incontrollable. These forces are chemical as well as mechanical.

Corrosion is the strongest destructive force to which a boiler is subjected, and is of two kinds — external and internal.

Internal corrosion can be divided into three classes, known as: uniform corrosion or wasting; pitting or honey-combing; and grooving; so named from the appearances they present.

Uniform corrosion is that species of wasting of the plates, tubes, etc., where the water corrodes them, in a more or less even manner, in patches of large extent, and where there is usually no well defined line of demarcation between the sound and corroded part. It is like ordinary rusting in its character and effects, but is seldom so uniform. This is easily detected, and even when covered by a thick coating of incrustation, on emptying a boiler, it is shown by red streaks where the scale is cracked, or "bleeding" as it is sometimes called. But when detected, owing to its uniform appearance, the depth to which it has penetrated can only be determined by

drilling holes through the plates and measuring the thickness.

Corrosion is apparently very capricious in its action. Two boilers, made exactly alike, of the same iron, and fed with the same water, and subjected to the same amount of work, will be differently affected. One may be attacked in the bottom, the other at the water line. Doubtless the differences in the qualities of the plates have much to do with this. From experiments made by Drs. Whelpley and Storer, some years since, it was found, that in specimens cut from the same plate of iron the heat-transmitting qualities varied by from ten to forty per cent., showing decidedly that the structure and qualities of a plate of iron are not homogeneous.

Again in some places boilers will be attacked generally on the shell, and in others they will suffer principally in the tubes, and in other places still, the rivet-heads and seams suffer most. Sometimes the stays waste more rapidly than the plates. This action, so erratic, of the corrosive agents must be ascribed to their gravity, their concentration in certain parts, to the circulation of the water, to the nature of the iron, and other more obscure causes.

In many boilers supplied with water containing sulphate of lime, when scale is detached a black coating of oxide of iron is found adhering to the scale, which as often as it re-forms and is detached brings with it a fresh film of the oxide.

Another peculiarity may be noticed — that whereas in most cases the corroded iron is readily removed, yet cases

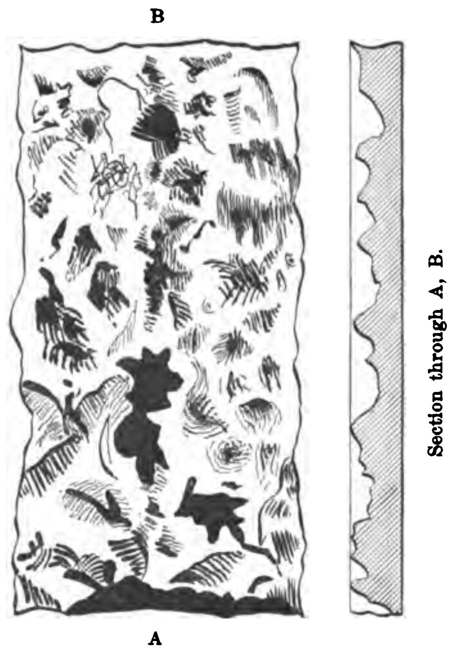


PLATE IX. Pitting.

often occur where the corroded iron adheres most tenaciously to the sound iron beneath it, so that considerable force is required to remove it, and the presence of corrosion may not be even suspected until the pick or hammer is forcibly applied.

Pitting and honey-combing are well marked by the sharply defined edges they present. The term honey-combing is generally used to describe the appearance of plates indented by very small holes close together. Pitting is confluent honey-combing, and is found in patches of various sizes, varying from one half an inch to twelve inches or more in diameter, and from one-sixteenth to one-fourth of an inch in depth, and of very irregular forms.

This form of corrosion is very eccentric in its attacks, as it may be found on every plate in the boiler in contact with the water, and sometimes in the steam spaces and domes; or, it may be found on a single plate either above or below the water, whilst the remainder bear no traces of corrosion at all.

Various reasons have been rendered for this mode of corrosion, but none of them appear to be altogether satisfactory. Galvanic action was supposed, for a long time, to be the prime cause of pitting, but that theory has been almost entirely abandoned now, and it is conceded generally that pitting is due to simple chemical action.

It is well known that the concentrated acids of the water will attack the most susceptible portions of the plates; and if the acids are volatile, or the liquid acids are carried, by foaming and priming, into the steam space, the plates there also will suffer. The wasting of

plates round the holes for the stays is principally due to the injury to the material when punching the holes, which renders the metal more susceptible to the action of the water.

The surest way to prevent internal corrosion is to abandon the use of water which produces that effect; but this is not always entirely practicable.

When the water is found to affect the plates only in particular places, as at the water-level, it is well to use thicker plates at such places, and to arrange them so that the seams do not come within the region attacked by the water.

When there is no choice of feed-water, the acids may be neutralized and corrosion prevented by the use of some alkaline substance prior to the introduction of the feed-water into the boiler. This is best done by using soda ash, or carbonate of soda, which should be dissolved and introduced with the feed-water into the boiler. The quantity required will vary according to the strength and quantity of the acids in the water, and can be best ascertained by experiment.

Grooving, channeling, or furrowing, as it is variously termed, is due to mechanical action produced by unequal expansion. Where it is not aided by the corrosive action of the water, it may penetrate deeply into the plate without being more than one-sixteenth of an inch in width at the surface, and sometimes the grooving is so fine as to appear like a fracture. The introduction of the feed near the water-level in the boiler, instead of near the bottom, helps materially to prevent grooving.

Internal grooving is undoubtedly often induced by careless or excessive caulking, which destroys the skin of the iron, and thus exposes a surface to the attack of the corrosive agents in the water.

External corrosion is a more subtle agent in the destruction of stationary boilers than any kind of internal corrosion, and this is because its presence is less suspected, and it is not easily to be detected on account of the difficulty of getting at the plates.

Improper setting in brick-work often causes corrosion, the part of the boiler-shell exposed to the action of the probably impure lime having been badly eaten. And external corrosion is caused by exposure to the weather, leakage at joints, leakage of fittings, drippings from pipes, etc., moisture from wetting ashes near the boiler and moisture rising from the ground, etc. Cooling off the boiler too rapidly and filling it when it is warm are productive of leaky seams, and hasten the destruction of a boiler.

The tube ends are a source of annoyance in some types of boilers, and this is especially apt to be the case with boilers of the vertical type.

The upper ends are exposed to the action of the heated gases, and there being no water to prevent over-heating, they are soon loosened and commence to leak badly. This gives rise to corrosion of the ends of the tubes and the upper head, which in many cases goes on with great rapidity. It is no unusual thing to find the upper tube-sheet of upright boilers eaten half-way through, and nearly all the tubes leaking badly. This leakage is not so

apparent from steam pressure as it is from water pressure. To the unpracticed boiler attendant everything may appear all right, but when the boiler is filled to the top with water, and pressure is applied, there is generally trouble.

The lower ends of tubes are also very apt to give more or less trouble, especially when the upright boilers are used for heating purposes, and the blow-off does not quite drain the boiler. For, during the summer months, when the boiler is idle, the interior of the shell and tubes, just at the surface of the water left in the boiler, are subjected to severe pitting. Sometimes the tubes of this class of boilers are completely riddled in a very few seasons, whereas, if properly cared for, they should last many years. Where the upper ends of the tubes are loosened from the action of heat, they may be made tight, if they are not too much corroded, by expanding; but, when they are pitted, and the holes extend clear through, the only remedy is a new tube.

EXPLOSIONS

EXPLOSIONS of steam-boilers are due to natural deterioration, to defects of construction, or to faulty management. Explosions take place when, at some point, the resistance is less than the pressure to which it is subjected. Explosions occur even at very low pressures.

The pressure of the steam is never increased in a boiler unless through the natural increasing effect of the furnace. No phenomenon exists that has power to suddenly increase the pressure in a boiler. The action which has been attributed in this respect to the "spheroidal state," and to the "superheating of the water," has not been confirmed by observation.

The explosion of a boiler is not instantaneous in its action. The rupture commences at the point where the resistance offered by the material is less than the strain to which it is subjected. It is extended into the contiguous parts when these parts are too weak to sustain this increased strain that the rupture, already made, brings to bear upon them, and to the shock due to the motion that the edges of the fracture make while seeking a new state of equilibrium.

The number and direction of the ruptures depend especially upon the resistance of the parts adjacent to the first

fracture. A rupture, even of considerable extent, does not produce an explosion if the contiguous parts possess sufficient strength.

In case of an explosion, the steam pressure does not fall immediately that the rupture takes place. On the contrary, the pressure continues very nearly constant up to the time when all the water has escaped from the boiler.

The explosion is so much the more terrible as there are more fractures made prior to the moment when the boiler is entirely emptied of its water.

It is dangerous to let the water get so low in a boiler that the plates become red-hot, because then the softened plate tears open and produces an explosion, if the red-hot part is of large extent, or if the adjoining parts do not offer sufficient resistance.

When water is fed into a boiler where the water is too low, it almost invariably lowers the pressure of the steam. It is always dangerous to introduce feed before having drawn the fires, or dampened them with wetted small coal or ashes, because the water injected quiets the ebullition, and increases the surface exposed to the heat.

There is not, nor can there be, any connection between the explosion of steam-boilers and the phenomenon known under the name of "the spheroidal state."

Even when "low water" does not cause the plates to be heated to redness, it causes leakage and fractures, by reason of the unequal contraction and expansion produced.

Low water can only be prevented by constant vigilance on the part of the person in charge.

It is dangerous to empty a boiler when the flues or tubes are still hot, and to fill a boiler with cold water before it becomes sufficiently cooled off.

Such action causes fractures of the transverse riveting in such a manner as may not always be shown by leakage, and this defect may very easily produce an explosion when next the fires are lighted, or in a short time afterward.

It is dangerous to fire up under a boiler too rapidly. When the draught and the combustion are sufficient for a "white heat," the plates, no matter how good they are, cannot resist with certainty.

Explosions, as aforesaid, are due solely to natural deterioration of the boilers, to defects in construction, and to the unskillfulness of those who manage them. They are due for the most part to unseen defects, because no one has tried to discover them.

In Newark, N. J., a short time ago, the water got low in a new and strong boiler from inattention on the part of the engineer, and many of the tubes were required to be reset; but no inspection of the boiler was made or attempted. A few months afterward it exploded with violence shortly after the feed had been put on, doing serious damage.

The hydraulic pressure applied to a boiler does not show us whether it is dangerous to use the boiler or not.

Many boilers have exploded when corrosion has reduced the metal to such a thickness that a smart blow from a ball-faced hammer would have gone through the sheet,

while the boiler has shown tight when under hydraulic pressure.

An internal inspection of boilers is the only means of ascertaining their condition. When this inspection is thoroughly made, we can tell whether the boiler is safe or not, and in no other way.

Every part of a boiler may contain dangerous defects, and an examination is only finished when every part of the boiler has been carefully inspected.

When a plate is covered with soot or incrustation, most of the defects cannot be seen; therefore it is highly important that boilers should be kept as clean as possible, as well externally as internally.

It is a very bad plan to hasten the cooling of a boiler, particularly when it is a long one. Especially is it necessary never to let the water out of a boiler until the tubes, or flues, are sufficiently cooled down.

From what has been said before, it is plain that a boiler may burst and not explode, but that an explosion is always preceded by a bursting, to which the explosion is a consequent.

The various steps in an explosion may be described as follows:

First.— A fracture in a plate followed by a rending.

Secondly.— A violent outburst of steam and water.

Thirdly.— A fall in pressure.

Fourthly.— Portions of the water are propelled with great violence against the shell of the boiler, which is shattered thereby.

Fifthly.— The steam generated by the liberated water imparts a high velocity to the fragments, converting them into projectiles, and thus spreading ruin and destruction around.

Unequal expansion or contraction is often the cause of rupture. In one case that came under the writer's notice, a large boiler on an ocean steamship was fired up the day previous to her regular sailing-day, and steam was raised to 10 lbs. pressure; but the water bottoms were sufficiently cool for a person to keep his hand on them, and a few hours later one of the girt seams of rivets opened out for about three or four feet in length. This was owing to imperfect circulation of the water in the boiler, causing unequal expansion and the consequent rent. Even while running in regular work, it has been found that, by inserting thermometers in different parts of a boiler, there was a wide variation in the temperature observed.

Another source of explosion is due to the sudden and unequal expansion of the metal of large cast-iron stop-valve chambers when steam is suddenly let on in cold, frosty weather through opening the valve, water of condensation being present. Such explosions have taken place with only 10 lbs. steam pressure.

Boilers can be exploded also from a preliminary explosion of gas in the flues or furnace.

Experience has shown clearly that the great majority of accidents and explosions happen to uninspected boilers.

It is generally said by those not thoroughly conversant with steam that, in case of an explosion, the water must

have been low; and they point, in corroboration of their statement, to the fact that no water is found scattered round. It is true that all of the water in the boiler cannot be converted into steam, for 965 units are required to boil water into steam from and at 212° Fahrenheit; while at 140 lbs. pressure the temperature would be 361°, or 149° units higher than 212°. Now 965 divided by 149° is 6½ nearly. That is to say, of every 6½ lbs. of water in the boiler, *one pound* only will be thrown into steam of atmospheric pressure, while 5½ lbs. will be scattered in the air mixed with the resulting escaping steam.

Probably less than one per cent. of all the boilers made explode, but many more are ready to fail either quietly or violently from causes which may be easily discovered by competent inspection.

From various experiments, the following conclusions have been arrived at:

1. A violent explosion may take place in a boiler when there is plenty of water in it.

2. A moderate pressure of steam may produce a terrific explosion when there is plenty of water.

3. That a boiler may explode under steam at a less pressure than it has stood without apparent injury from a water pressure.

4. A rupture will be followed by relief of pressure with or without explosion as the fracture is extended or restricted.

A committee was appointed in France, under the supervision of M. Hirsch, to investigate the "super-heated

water" theory of boiler explosions. They made three series of experiments, occupying months, and concluded that *super-heating of water could only be responsible for explosions under very exceptional circumstances.*

A committee was appointed by the late Chas. J. Folger, while Secretary of the Treasury, to investigate the method of preventing super-heating of water in boilers. The method consisted of putting a perforated diaphragm in a boiler, a short distance above the water-line, and securing it by rivetting to the boiler-shell. The committee reported in favor of the method, but, unfortunately for the claims of the patentee, their report showed enough other reasons for the explosion of the boiler in their statement of the facts of the case. And again, they did not prove that if a boiler, without a diaphragm, had been subjected to similar treatment, and had afterward been supplied with one, that the diaphragm would prevent the explosion; and finally, they did not prove that the water was super-heated at the time of the explosion.

The formation of the committee was not of the ablest engineers in the country, and their opinion on the question must be received *cum grano salis.* It will take something more than a report emanating from such a source to contradict a long series of investigations carried on by distinguished *savants.*

DEFECTS

IT is not attemped to give, in these pages, a full list of all the defects that may be found in steam boilers—but the more prominent ones only are mentioned, together with a few directions how to act when they are discovered.

LOOSE RIVETS.—This is generally due to overheating, but not always; they should be cut out and new ones driven.

BLISTERS.—These are due to imperfect welding in the manufacture of the plates. They should be trimmed off to ascertain their extent and thickness, and, if of small area and slight thickness, are not dangerous; but, if of considerable thickness and large area, or if the plate is cracked under the blister, they must be cut out and a "hard patch" put on. Sometimes blisters are so large that an entire plate has to be removed and a new one substituted.

BURNT PLATES.—These are generally due to sediment or scale, but sometimes to an incrustation formed from oily matter. The place should be cut out and a hard patch put on.

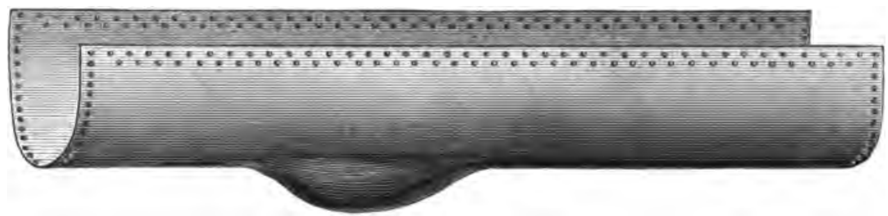


PLATE XI. Bagging.

Bagging, buckling, or bulging of plates generally occurs from over-heating in consequence of deposits of oil, sediment, or scale. Sometimes it occurs when the boilers are clean, and then it is the result of the impact of flame, or it may be caused by the unequal expansion of the various laminæ of the plates under their daily usage, as there will be no signs of over-heating. It is also very liable to occur in the flat fire-sheets of the sides of fire-box boilers when the stays are spaced too far apart; a usual remedy in this case is to put in an additional stay-bolt between each four stays already there. The presence of a bulge on the bottom fire-sheet of a boiler is not necessarily dangerous, but it must be watched carefully—and its surfaces kept clean—and at the first indication of weakness must be cut out. and a hard patch put on.

Seam Leaks are fair evidence of over-heating; they should be carefully examined, rivets cut out, if necessary, and re-driven, and the seam carefully caulked.

Cracks in plates may be due to over-heating, or to unequal expansion and contraction, or to too rigid staying. Again, cold water impinging on the plates often chills the iron, which, being afterwards heated, produces a short temper in that portion of the sheet, and will often result in a crack, and may lead to an explosion. As a rule, it is safe to say that accidents, from the over-heating of boiler surfaces, do not occur at the moment of over-heating, but at some subsequent period. How soon, depends upon the

extent of the over-heating, and the damage which it is allowed to work. Steam boilers can be used with almost perfect security if proper attention is paid to them, requiring merely a careful observance of natural laws, and the constant exertion of that much neglected faculty, common sense.

As a general rule, high-pressure boilers, so called, are more carefully built than those designed for low pressure, but the strains in them are greater. It must never be forgotten that the strength of a boiler is only that of the weakest part in it. Too much care cannot be taken with any boiler, for no boiler is accident-proof.

Neglect of the masonry in the setting of a boiler often is the cause of external corrosion, and cracks or loose bricks should never be allowed. Great waste of fuel often ensues from air leaking into the flues, and the draught is always vitiated and the heating surfaces cooled.

To diminish liability to accident from imperfect material, it is well to have strips cut from some of the plates designed to be used in the construction of a boiler, and to have them tested for tensile strength and ductility. For all marine boilers the plates are required by law to be so tested, and many makers of stationary boilers, as a self-protective measure, are in the habit of having samples tested from the plates of every boiler they build. It would be well if this custom should become general.

In England the Manchester Steam Users' Association have introduced severe tests for boiler-plates. The pulling or extension tests are applied by means of a testing

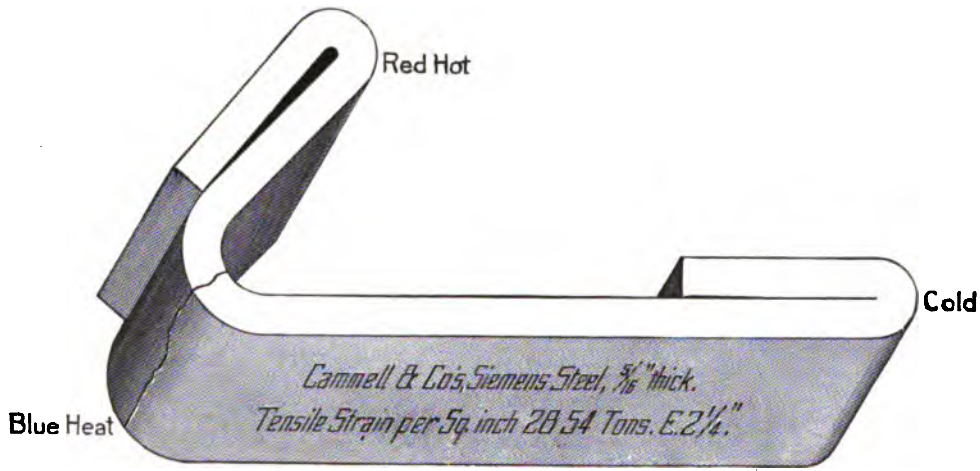

Red Hot
Cold
Blue Heat
Cammell & Co's, Siemens Steel, 5/16" thick.
Tensile Strain per Sq. inch 28.54 Tons. E.2¼."

PLATE A.

machine, and the strain is increased until the samples from the plates are torn asunder, in like manner as boiler-plate samples are tested by the United States Inspectors of Steam Vessels. The elongation, as well as the greatest tensile strain, is noted. The bending test is, if anything, more rigid. Strips are taken of from six to nine inches in length and an inch in width; they are heated to a low cherry-red and then plunged into water of about 80° Fahrenheit. When cold they are bent double, the rule being that every one must hinge on a curve having a radius of not more than one and a half times the thickness of the strip, and it is expected that the bending will be accomplished without any sign of failure being visible.

It has been found that steel boiler-plates as now made are, as a rule, much more ductile than iron plates. Strips cut from iron boilers have, on being tested, in some cases behaved most unsatisfactorily. They fractured on bending at the slightest departure from a straight line, and, on being pulled asunder, broke short off without any elongation, showing that they were of a very brittle character and unfit for use in a boiler. Short brittle plates are apt to give rise to dangerous cracks, which lurk at the rivet-holes and lie concealed under the overlap, till in the course of time a rip suddenly occurs and causes an explosion.

Iron boiler-plates, however, made in this country are of a much better average quality than English plates, ranging in tensile strength from 45,000 lbs. to 70,000 lbs. per square inch of section, and having a high grade of ductility.

Experiments made in testing steel boiler-plates in the 2d U. S. Inspection District show that they ought to possess a ductility amounting to at least fifty per cent. reduction of area, no matter what the tensile strength may be, in order to avoid cracks in the plates when put to use.

Experience shows also, that steel plates in large boiler-shells should always be butt-strapped on both sides.

The following is the rule adopted by the Board of U. S. Supervising Inspectors for testing plates for boilers:

"To ascertain the tensile strength of the plates, the inspectors shall cause a piece to be taken from each sheet to be tested, the area of which shall equal one-quarter of one square inch on all iron five-sixteenths of an inch thick and under; and of all iron over five-sixteenths of an inch thick the area shall equal the square of its thickness; and the force at which the piece can be parted in the direction of the fiber or grain, represented in pounds avoirdupois — the former multiplied by four, the latter in proportion to the ratio of its area — shall be deemed the tensile strength per square inch of the plate from which the section was taken; and should the tensile strength ascertained by the test equal that marked on the plates from which the test pieces were taken, the said plates must be allowed to be used in the construction of marine boilers; provided always, that the said plates possess homogeneousness, toughness, and ability to withstand the effect of repeated heating and cooling; but should these tests prove the said plates to be overstamped, the lots from which the test-plates were taken must be rejected as failing to have the strength stamped thereon. But nothing herein shall be so construed as to prevent the manufacturers from re-stamping such iron at the lowest tensile strength indicated by the samples, provided such re-stamping is done previous to the use of the plates in the manufacture of marine boilers.

"To ascertain the ductility and other lawful qualities, iron of 45,000 pounds tensile strength and under, shall show a contraction

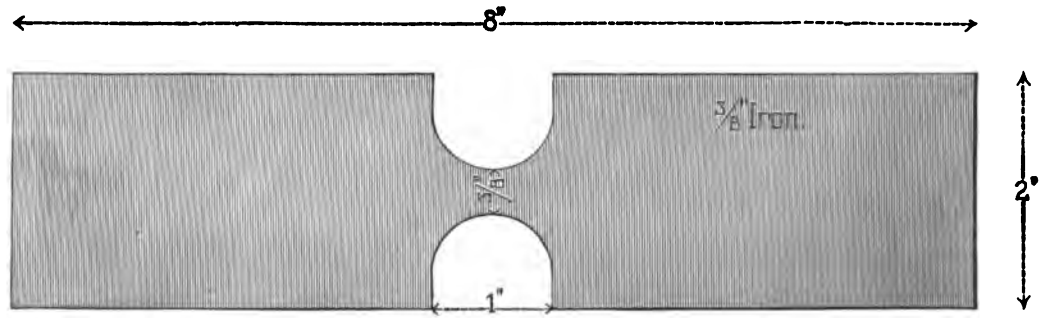


PLATE X. Sample Piece for Testing.

of area of fifteen per cent., and each additional 1000 pounds of tensile strength shall show one per cent. additional contraction of area, up to and including 55,000 T. S.

"In the following table will be found the widths — *expressed in hundredths of an inch*,— that will equal one-quarter of one square inch of section of the various thicknesses of boiler-plates. The signs + (plus) and — (minus) indicate that the numbers against which the signs are placed are a trifle *more* or *less*, but will not in any case exceed one-thousandth of an inch.

"The gauge to be employed by the inspectors to determine the thickness of boiler-plates and the widths in the table will be any standard American gauge furnished by the Treasury Department.

$\frac{3}{16}''$ = 133 —	.26 = 96 —	.35 = 71 —
.21 = 119 —	.29 = 86 —	$\frac{3}{8}''$ = 67 +
.23 = 109 +	$\frac{5}{16}''$ = 80	$\frac{7}{16}''$ = 57 —
$\frac{1}{4}''$ = 100	.33 = 76 +	$\frac{1}{2}''$ = 50

"All samples intended to be tested on the Riehle, Fairbairn, or other reliable testing-machine, must be prepared in form, according to the diagram herewith given, viz.: eight inches in length, two inches in width, cut out at their centers in the manner indicated."

In the English navy it has been decided to adopt steel for all future boilers.

At certain temperatures steel loses its ductility and becomes brittle. This fact was announced by Mr. Daniel Adamson at the meeting of the Iron and Steel Institute at Paris in 1878.

Recently, Mr. G. F. Barnaby, Admiralty inspecting-officer at the works of Charles Cammell & Co., confirmed Mr. Adamson's statement, by a series of experiments made for the British Admiralty. Sixty-eight specimens of

Siemens-Martin and Bessemer mild steel were used from different makers.

The results showed that at certain temperatures (about 550° Fahr., according to Mr. F. W. Dick, of the Steel Company of Scotland), varying between a light straw and a light blue color, it is extremely unsafe to work mild steel for any purpose, as every specimen broke on being bent.

Below is given a comparison of tests of steel plates made by the Steel Company of Scotland and American steel of all the prominent makers:

Maker.	*No. of Test-pieces.*	*Tensile Strength.*	% *Reduction of Area.*	*Experimenter.*
Steel Co. of Scotland.	Not known.	65,632	49.1	Kirkaldy.
American ...	118	65,811	54.2	U. S. Inspectors.

The parties furnishing the samples of steel were Park Brothers & Co., of Pittsburgh, the Cambria Iron Works, the Otis Steel and Iron Co., Cleveland Rolling Mills, Nashua Steel and Iron Co., Bay State Steel and Iron Co., and Norway Iron and Steel Co. It will be seen that the American steel possesses the most ductility. The samples varied in tensile strength from 60,241 lbs. to 75,048 lbs., and in ductility from 44 to 81 per cent. Diagrams are inserted showing appearance of sample pieces tested for the Admiralty, and also of a sample taken from a piece of boiler-steel of an American steel firm, mentioned above, and subjected to exactly the same tests by the writer.

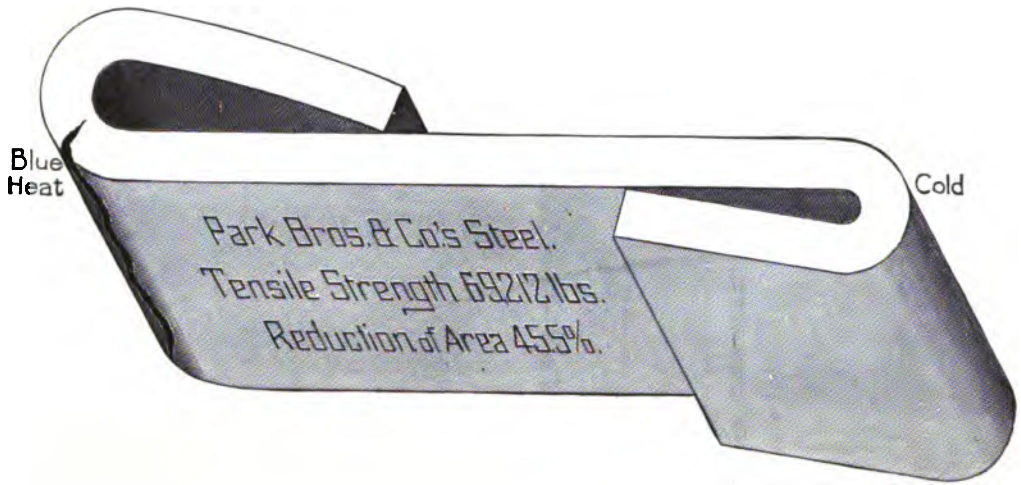

Blue
Heat
Park Bros. & Co's Steel.
Tensile Strength 69212 lbs.
Reduction of Area 45.5%.
Cold

PLATE E.

BOILER MANAGEMENT:

TO manage a boiler properly is of fully as great importance as to have it properly built. A boiler is always liable to get out of order, and it may become dangerous, and it is especially necessary to know what to do in such cases.

The fireman's duties are generally undervalued, yet they call for more knowledge than is generally supposed. To attend to his duty properly, he should know his business thoroughly, be prompt, reliable, careful, and last, but not least, sober.

Experience only can teach a man how to fire, with the different kinds of fuels, in the best and most economical manner under the various styles of boilers.

It is essentially necessary that the boiler-room, with the tools and appurtenances, as well as the boilers and fixtures, should be kept clean. Every tool should have its place, and be kept there when not in use.

Before starting the fires under a boiler, the fireman should see:

1. That there is sufficient water in the boiler — not only by looking at the glass water-gauge, but by trying the gauge-cocks.

2. That the furnaces and flues are clear, and that grate-bars are not broken or warped badly (in which case they must be removed and new ones substituted).

3. That the upper gauge-cock is open, to allow air to escape while steam is forming.

4. That the blow-cock is shut.

5. That dampers and doors move freely.

6. That the boiler hand-pump, if there is one, is in good working condition.

7. That the glass water-gauge is clear and shows the true water-mark.

He should then cover the grate-bars with a layer of coal, beginning at the bridge-wall and extending two-thirds of their length toward the furnace-door; then, on the open part of the bars, he should pile his wood, cob-house fashion, put a few lighted shavings or oily waste in the mouth of the furnace, partially close the furnace-door, and wholly close the ashpit-door. The coal in the back end of the furnace prevents a draught of air from coming through the bars and injuring the draught of the burning wood — and the furnace-door being kept partly open furnishes air to the wood, and directs the flame over the coal in the back end of the furnace, gradually heating it up to the point of ignition. After the wood is fairly burning, coal may be thrown on it, and the furnace-door wholly closed, and the ashpit-door opened. More coal is thrown on as soon as the fire will bear it, and the fire is gradually pushed back, till there is a full fire on the whole length of the bars.

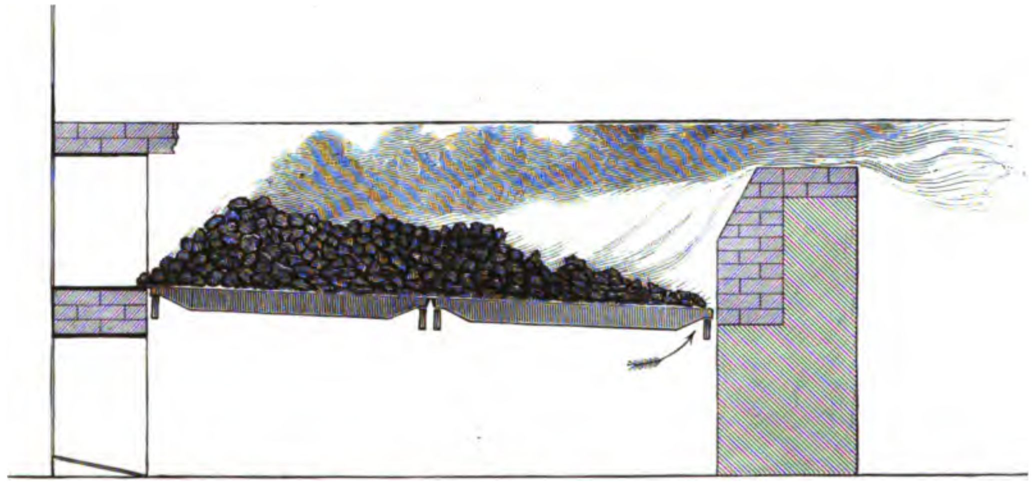


Plate XII. Improper Firing.

In firing with "hard," or anthracite, coal, a thickness of from six to eight inches should be kept on the bars; with "soft," or bituminous, coal, the thickness should be from eight to ten inches; and with coke, from ten to twelve inches.

The fires should always be kept level and of uniform thickness, with this exception, that at the corners, sides, and bridge-wall it must be enough thicker to prevent cold air from leaking through in those places.

After the fire is started, and steam has commenced making, he should try his safety-valve, to see that it moves freely, and examine joints for leaks.

The fire must not be hurried; it must be allowed to come up very gradually, and to do this in the best manner, *put on only a little coal at a time.* The fire will be more even for it; and remember, that if the coal is lumpy it must be broken so that no piece is larger than a man's fist.

The firing is only done properly when the fuel is consumed in the best possible way — that is, when no more is burned than is necessary to produce the amount of steam required, and to keep the pressure uniform.

To attain this end, complete combustion must be obtained in the furnace, and this is going on when the fuel is burning with a bright flame evenly all over the grate.

Blue flames, dark spots, and smoke are evidences of incomplete combustion, due to want of air, which must be supplied above the fuel in the furnace, as well as below through the bars.

When the fires are well going, they should be fired at regular intervals and lightly, and it has been found better in many cases, to fire only one side of a furnace at a time, but of this each fireman must be his own judge, from his own experience. No two boilers can be fired exactly alike and produce the same results.

The firing must be done quickly, keeping the furnace-door open as short a time as possible.

The ashpits must be raked out frequently, and the air spaces between the bars must be kept free also. All ashes must be hauled to some distance from the boiler fronts and quenched, and then wheeled to the ash-pile.

The fire should not be stirred any more than is necessary, in order to avoid the waste of small coal dropping through the bars. With a strong draught it is well to partially close the damper while firing, to avoid contraction of the boiler sheets as much as possible, or to partially close the ashpit-doors for the same reason.

When the clinkers and dirt accumulate to an extent sufficient to clog the draught, the fire should be cleaned. Now, in land boilers the furnaces are very wide generally, and it is as well to clean only one-half at a time, by breaking up the clinker with a slice-bar, and then hauling it out with a rake, then firing lightly, doing the whole as quickly as possible. A fire should run without cleaning, with good coal, about twelve hours.

Never close the *damper, especially at night,* while there is a fire on the grates, as gas may collect in the flues, and if the fires are banked, and should blaze up, an explosion of the gas might take place and ruin the boiler. There is

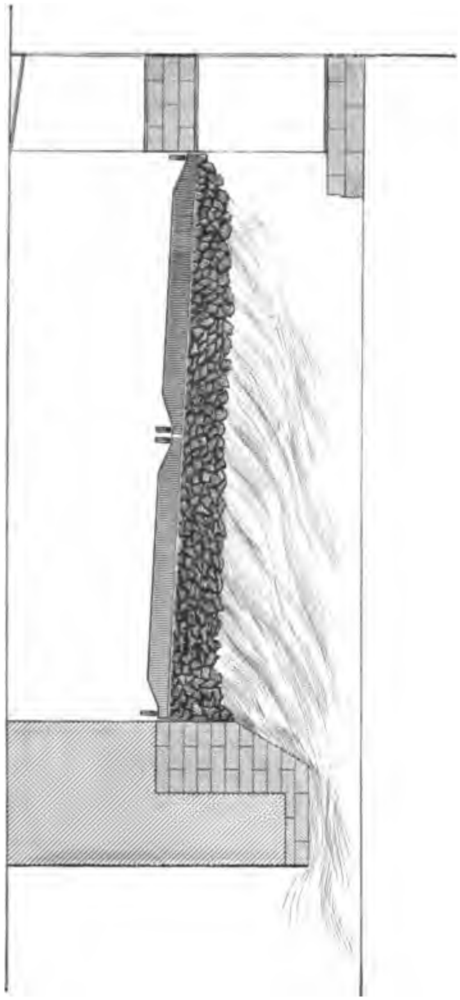


PLATE XIII.

reason to believe that boiler explosions have been produced in this manner—and, for this reason alone, it is better to draw the fires at night, when work is stopped, and rekindle them in the morning.

After the fire is hauled, the furnace and ashpit-doors should be closed and also the damper, in order to prevent the boiler from cooling too rapidly.

When there are several furnaces to be fired—all leading into one chimney—they must be alternately fired in order to keep steam at a regular pressure and observe the greatest economy.

The fuel should be kept as dry as possible—under shelter—and out of the sunlight.

The practice of wetting coal before throwing it into the furnace cannot be too severely condemned, as it is wasteful of heat and produces corrosion.

The boiler, flues, and furnaces should be cleaned frequently—to avoid loss of heat, which means waste of fuel.

Blowing off steam at the safety-valve, or opening the furnace-doors, to prevent a rise of steam-pressure, causes loss of heat, and will never occur where a fire is properly managed, except upon an emergency.

A boiler should have its feed-water continuously and regularly supplied, and the water-line should be kept at regular height, and there should never be less than three or four inches in depth over the highest part of the furnaces, flues, or connections exposed to the flame or hot gases.

When a boiler is cold and filled with water, it will be found that, after the fire is lighted and steam is raised to

the regular pressure, the gauge-cocks and water-glass show a higher water-level than before the fires were started; this is owing to the expansion of the water by heat. Now if the throttle be opened and the engine started, the water will rise still higher in many boilers, showing a *false water-line*—for the water will drop to its proper level upon stopping the engine. This is owing to the violent ebullition going on in the boiler—to supply the steam required which is being constantly drawn off—and it is more marked when the steam-room is small and the pressure is high.

In order to save fuel the feed-water should be heated, if practicable.

The steam-pressure never should be allowed to exceed the highest limit. If the steam-gauge shows that the steam-pressure is rising rapidly, and that there is danger of exceeding the limit, water should be fed in at once, and the draught checked by the damper or ashpit-doors; and if the pressure should exceed the limit, the furnace-doors should be opened, the ashpit-doors nearly closed, and the feed started, unless the water is so low that there is danger from that, in which case the feed must not be started.

A boiler needs cleaning out more or less often during a year, dependent upon the amount of impurities in the feed-water.

When a boiler is to be cleaned out, *the water must not be blown out by the pressure of the steam.* The water must be allowed to remain in the boiler until it is cool, and then it must be permitted to run out through the hand-holes and blow-off cock. The scale must be knocked off with

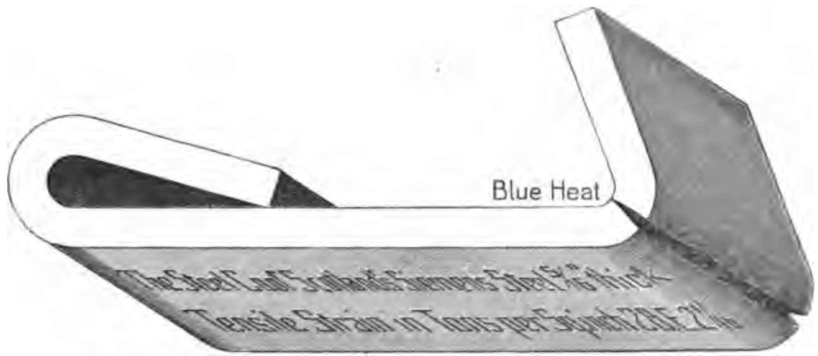


PLATE B.

light blows of the hammer, or scraped with chisels, or loosened with angular wire chains, etc.; and the boiler must be washed inside with clean water. The scale should be removed as soon as possible after the water has been let out of the boiler, before it has time to dry and harden.

When the boiler is cleaned, the blow-cock should be taken apart and the plug cleaned and oiled, and made to work water-tight and easily; the check-valves should be examined, and made tight if leaky; the feed-pipes and blow-out pipe should be examined and cleared of sediment, if any exists. If the safety-valve has been found to work imperfectly, or to leak steam, advantage should be taken of the boiler's not being in use to examine the pins, clean and oil them, to clean and oil the guide, and to grind in the valve.

After the boiler has been cleaned, and the flues and connections swept, it should be seen that the braces are not badly wasted by corrosion, or sheets pitted, or rivet-heads eaten away, etc.; that the packings of the man-holes, hand-holes, and pipe-flanges are in good order.

Don't leave old lamps, blocks of wood, overalls, bags, etc., in the boiler.

Remedy all defects as soon as found, when it is possible to do so.

If you find that your feed-water causes considerable incrustation, you can prevent it to some extent by using a scum-pan in the boiler near the surface of the water, connected by a pipe passing through the boiler-shell. A couple of inches or less of water blown off at morning, noon, and night will aid very materially in reducing the

amount of scale. Blowing out from the bottom is of very little use in removing scale or sediment.

All the water should never be blown out of a boiler, except as an actual necessity, and then never should be done under a higher pressure of steam than ten or fifteen pounds. But the fire should always be drawn before the blowing-out is attempted; and the doors and dampers must be closed to prevent too rapid cooling; also, to prevent the formation of a vacuum from the condensation of the steam in the boiler after blowing out, a gauge-cock must be left open — unless an air-valve is fitted — which works the reverse way of a safety-valve.

In refilling a boiler after cleaning or blowing out, when *cold* water is used it should be let in very gradually, and not until the boiler is cool. When hot water is used, the boiler should be hot also, in order to avoid the danger of contraction and expansion. When a boiler is not to be used for some time, the water should be let out, the hand-hole and man-hole plates taken off, and the boiler thoroughly cleaned and dried; and, to protect it from moisture, a light fire of shavings should be kindled in the ashpit about once a week, or else it should be filled quite full of water. The furnaces, flues, and connections should be swept clean; ashes and clinkers should be raked out and carried away, and any defects in the masonry made good.

The cocks, valves, and all copper or brass pipes or fittings should be kept clean and bright. The floor, ceiling, and walls of the boiler-room should be kept clean also, and the boiler should be wiped off regularly.

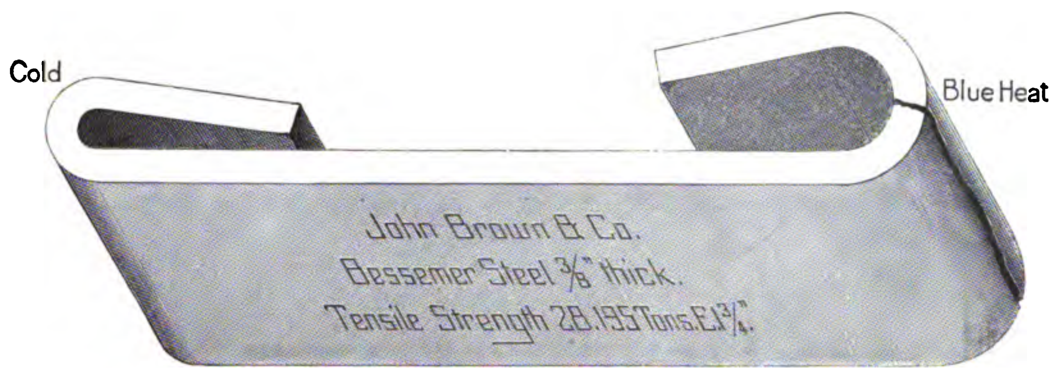

Cold
Blue Heat
John Brown & Co.
Bessemer Steel 3/8" thick.
Tensile Strength 28.195 Tons. E.L. 3/4".

PLATE C.

"Foaming" is a violent ebullition of water in the boiler, which results in "priming," or the carrying of the water, in the state of fine spray, with the steam into the cylinder, often causing serious damage.

Foaming is generally caused by irregularity in firing or feeding; impure water, especially if it be greasy; contracted steam-space; too small extent of area at the water-line; the boiler not being clean; the throttle being opened suddenly; and in marine boilers, changing the feed-water from fresh to salt, or the reverse. It is shown by a sudden rising and falling of the water in the gauge-glass, or by a boiling or showering of the water down through the glass. It can be overcome by partially closing the throttle, opening the furnace-door, and feeding strongly.

When the feed apparatus works badly, there may be several causes for it, such as:

Leakage in suction or discharge pipes;
Broken or leaky valves on the pump;
Leaky packing;
The pump being hot;
The feed-water being too hot.

Should the water fall too low in the boiler, don't open the safety-valve, nor stop the engine if it is working; don't touch the feed-valve,—if it is open let it remain so; unless the fire is very light indeed, don't attempt to haul it, but spread a thick layer of wetted ashes or wetted small coal over the fire as quickly as possible, partially close the ashpit-doors, leave the furnace-doors open, and

allow the water to rise very gradually in the boiler till it regains its customary level.

Have the steam-gauge frequently tested, as it is liable to take a " set," as it is called, and may be several pounds out of truth. The safety-valve should be slightly and quietly raised from its seat every day, to see that it works freely and is tight. The load on it should never be increased.

To prevent accidents, the fireman must watch carefully that there is never too little water in the boiler, and that the steam-pressure does not exceed the limit. He must clean the boiler thoroughly and frequently, and see that the various parts and appurtenances of the boiler are in good working condition. He should always report to his superiors anything he suspects to be wrong about the boiler or its apparatus, as well as any defects, as soon as he can.

The fireman should have nothing to do except to attend to his boiler. If he has other work to do, his boiler will be neglected, and great waste of coal will result, to say nothing of extra wear on the boiler and the consequent expense of repairs and liability to explosion.


Cold
Cammell & Co.
Annealed Bessemer Steel, 3/8" thick.
Tensile Strength 33.64 Tons. E. 1 7/8".
Blue Heat.

PLATE D.

SAFETY VALVES.

A SAFETY-VALVE is designed to prevent the pressure in a boiler from exceeding a certain limit, by opening, when that limit is exceeded, and allowing the surplus steam to escape, until the pressure has fallen a little below that limit, when it closes.

In order that it may work efficiently, it is very necessary that it should be properly proportioned in all its parts.

Safety-valves are sometimes made with flat seats, as in the figure annexed, in which case, when raised, the

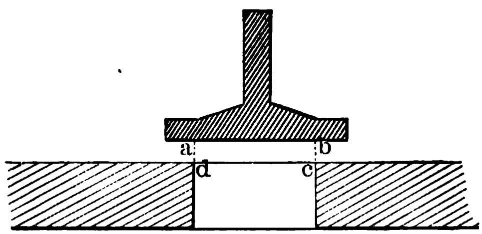


Fig. 1.

opening is equal to the surface of a cylinder having the same diameter, *ab*, as that of the valve, and a height equal to the lift of the valve, *ad*. So, to find the opening of a

flat valve, we must ***multiply the diameter of the valve by* 3.1416, *and that product by the lift.***

EXAMPLE.—A flat valve two inches in diameter has a lift of one-sixteenth of an inch. What is the area of the opening?

Diameter	2.00
Multiply by	3.1416
	6.2832
Multiply by one-sixteenth (0.0625)	0.0625
Area of opening in square inches	0.03927

But, if the valve has a bevel, as shown in Fig. 2, until it lifts clear of its seat the opening will be equal to the sur-

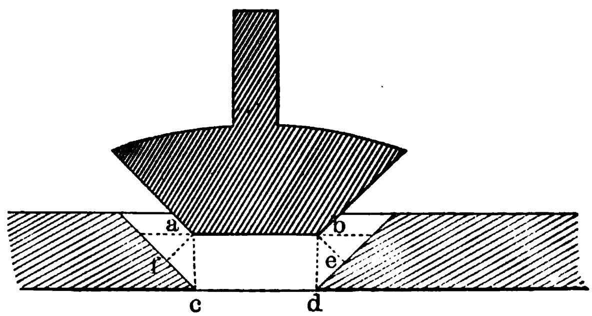


FIG. 2.

face of the frustum of a cone—having for the diameter of its upper base the diameter of the valve, *ab*, and for its slant height the perpendicular distance between the lower edge of the valve and the seat, and for the diameter of its lower base, the diameter of the seat, measured at the intersection of the perpendiculars, *be*, *af*, let fall from opposite points of the lower edge of the valve to its seat.

The bevel, or inclination of the valve, is the angle of inclination to a vertical line, *fca*, *edb*.

Now to find the amount of opening given by a valve with a beveled seat for any lift less than the depth of the seat, we have the following rule:

(1.) *Multiply the diameter of the valve by the lift, and that product by the sine of the angle of inclination, and that product by the number* 3.1416.

(2.) *Multiply the square of the lift by the square of the sine of the angle of inclination, multiply this product by the cosine of the angle of inclination, and this last product by the number* 3.1416.

Add these two products.

EXAMPLE.—The diameter of a safety-valve is four inches, the seat is one-half of an inch deep, and has a bevel of forty-five degrees. What is the area of opening for a lift three-sixteenths of an inch?

Diameter of valve..........	4.0
Multiply by lift ($\frac{3}{16}$)........................	.1875
	.7500
Multiply by sine of angle of inclination (45°)..	.707
	.53025
Multiply by 3.1416..........................	3.1416
First product................................	1.6658+
Square of the lift............................	.035156+
Multiply by square of sine of angle of inclination.	.499849
	.01757+
Multiply by cosine of angle of inclination	.707
	.0124+
Multiply by 3.1416.................	3.1416
Second product............................	0.039
Add first product....	1.6658+
Area of opening of valve in square inches.......	1 7048+

The most usual bevel for safety-valves is an angle of 45°, though 30° is frequently used. Mr. R. H. Buel gives the following short, but correct, rules for valves having seats beveled to 45° or 30° when the bevel is 45°:

1. *Multiply the diameter of the valve by the lift, and this product by the number* 2.22.
2. *Multiply the square of the lift by the number* 1.11.

Add these two products.

EXAMPLE.—What is the area of opening of a two-inch valve, for one-fourth-inch lift, depth of seat three-eighths of an inch; bevel of valve 45°?

Diameter of valve	2.0
Multiply by the lift	0.25
	.50
Multiply by 2.22	2.22
First product	1.11
Square of the lift	0.0625
Multiply by 1.11	1.11
Second product	0.069375
Add first product	1.11
Area of opening of valve in square inches	1.179375

For valves having a bevel of 30°:

1. *Multiply the diameter of the valve by the lift, and the product by the number* 1.57.
2. *Multiply the square of the lift by the number* 0.68.

Add the two products.

EXAMPLE.—A four-inch valve has a bevel of 30°, the depth of the seat is one-fourth of an inch. What is the area of opening for a lift of three-sixteenths of an inch?

Diameter of the valve	4.0
Multiply by the lift (three-sixteenths)	0.1875
	0.75
Multiply by 1.57	1.57
First product	1.1775
Square of the lift	0.035156 +
Multiply by 0.68	0.68
Second product	0.0239 +
Add first product	1.1775
Area of opening of valve in square inches	1.2014 +

Both of the above rules apply only to cases in which the lift is less than the depth of the seat. To facilitate calculations, a table of sines and cosines from 20° to 50°, both inclusive, is annexed:

Angle.	*Sine.*	*Cosine.*	*Angle.*	*Sine.*	*Cosine.*
20°	.342	.940	36°	.588	.809
21°	.358	.934	37°	.602	.799
22°	.375	.927	38°	.616	.788
23°	.391	.921	39°	.629	.777
24°	.407	.914	40°	.643	.766
25°	.423	.906	41°	.656	.755
26°	.438	.899	42°	.669	.743
27°	.454	.891	43°	.682	.731
28°	.469	.883	44°	.695	.719
29°	.485	.875	45°	.707	.707
30°	.500	.866	46°	.719	.695
31°	.515	.857	47°	.731	.682
32°	.530	.848	48°	.743	.669
33°	.545	.839	49°	.755	656
34°	.559	.829	50°	.766	.643
35°	.574	.819			

There are several rules for determining the proper area of a safety-valve for any boiler, and they are here given.

United States Steamboat Inspectors' Rule.

Allow one square inch of area of valve for every two square feet of area of grate, in the case of a common lever-valve.

English Rule.

For boilers with a natural draught, allow half a square inch of area in the valve for each square foot of grate surface.

French Rule.

1. Multiply the grate surface by the number 22.5.
2. Add the number 8.62 to the steam-pressure.
3. Divide the first quantity by the second. The quotient will be the area of the valve.

Professor Rankine's Rules.

Allow a valve of $\frac{6}{1000}$ of an inch for each pound of water evaporated per hour.

Rule adopted by the Philadelphia Department of Steam-Engine and Boiler Inspection.

1. Multiply the area of the grate in square feet by the number 22.5.
2. Add the number 8.62 to the pressure allowed per square inch.
3. Divide (1) by (2), and the quotient is the area of the valve in square inches.

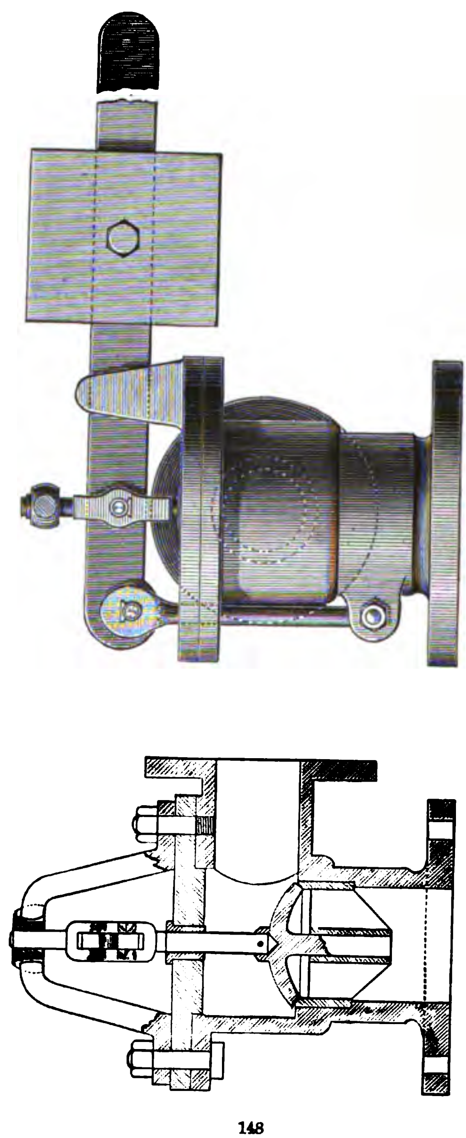
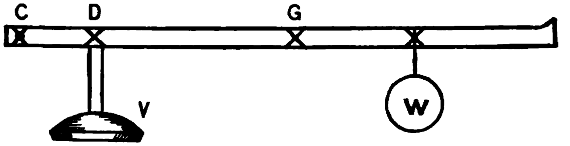


PLATE XIV.

Safety-valves are of three kinds, known as Common Lever, Dead-weight, and Spring-loaded.

The Common Lever valve is in more general use than the others, but it is imperfect in its action, as it will not seat until the steam-pressure has fallen several pounds below the point at which it is set to open; and, again, owing to the varying angle of the lever in a sea-way, the load on the valve is not constant, thus wasting much steam, so that its use is practically confined to stationary boilers. The plate shows this valve as approved by the Board of U. S. Supervising Inspectors of Steam Vessels.

The principle of this valve is that of a lever of the third order, the power to raise it being applied between the fulcrum and the weight. If the lever itself weighed nothing, it would be a very simple matter to calculate and adjust the position of the weight, but as both the lever and the valve are material, their weight forms an essential part of the calculation. The manner of making the calculation can be best explained by giving an example, illustrated by a diagram as follows:



Let AB represent a lever of a safety-valve forty inches long, and weighing ten pounds. Let the distance from the fulcrum C to the point of application D, of the power of the steam tending to raise the valve, V, be five inches; the distance from C to G, the center of gravity of the lever be

twenty inches. Let the diameter of the valve be four inches, and the weight be eighty pounds. Where shall the weight be placed on the lever, *i. e.*, at what distance from the fulcrum, in order that fifty pounds pressure per square inch may be kept upon the valve, supposing the valve itself to weigh five pounds?

As the valve is four inches in diameter its area is 12.56 square inches, and multiplying this area by 50 lbs., the pressure, we have a total pressure or power of 628.32 lbs. on the valve, which we must keep in place by the weight of the valve, of the lever, and of the weight on the lever. The valve acts as a dead weight, so by subtracting 5 lbs. from 628.32 lbs. we find we have only 623.32 lbs. resistance to be overcome, but this resistance is applied at five inches from the fulcrum, so we multiply by five and find we have 3116.60 lbs. The lever weighs 10 lbs. and acts with a leverage of twenty inches, thus making 200 lbs. of weight tending to keep the valve closed, and this subtracted from 3116.6 lbs. leaves 2916.6 lbs. to be neutralized by the weight. Now, if we divide 2916.6 by 80 lbs. we shall have 36.47 inches, the distance from the fulcrum at which the weight must be placed.

To test a lever safety-valve, when there is no steam upon the boiler, it is necessary to know where the center of gravity of the lever is situated. This may be found by disconnecting the lever and trying it upon a knife-edge, at right angles to its length, until the position is found where it balances, which must be marked, and its distance from the fulcrum measured, and the lever weighed, as also the valve, and the weight used as a load; and the diameter of

the valve must be measured. From these data the necessary calculations can be made. But there is a practical method of ascertaining the weight on a safety-valve, which is as follows:

Secure the valve stem of the safety-valve to the lever with a wire, but not rigidly; then affix a loop, into which you pass the hook of an accurate scale-beam; then secure the scale-beam so that it will take the weight of the lever and valve when weights are applied to it, and weigh the apparatus. The weight, as given on the scale, divided by the area of the valve in square inches, will give the pressure in pounds at which the steam will raise the valve. For small valves, an accurate spring balance may be used.

When a boiler is under steam, an accurate gauge can be attached to the steam-pipe, and the valve adjusted by means of that.

A dead-weight valve is a simple valve with a long stem, and is weighted by iron disks having a hole in their center for the stem to pass through, in order to secure them in place. In a sea-way they have the same defects as a common lever-valve. They can be tested by weighing the valve and the disks, and dividing the total weight by the valve area, or by the use of an accurate steam-gauge.

In a spring-loaded valve, the valve is kept in its seat by the pressure of a spring. This valve, no matter in what position it is placed, always blows off at the pressure for which it is set. There are many patents for different styles of this valve. The best of them, approved by the Board of U. S. Supervising Inspectors of Steam Vessels, gives so much larger a discharge opening than a common

lever-valve of equal diameter, that they have granted it fifty per cent. allowance of efficiency in excess of the lever-valve,— that is, one square inch of valve area only is required for every three square feet of grate. These valves have a valve seat beveled to 45°, and are nickel-plated, or have nickel seats, thus avoiding corrosion.

A great advantage possessed by spring-loaded valves lies in the fact that firemen cannot overweight them by hanging old pieces of grate-bars, etc., on them, nor shore them down on their seats, which can be and often is done where a common lever safety-valve is used; and, again, they will close before the pressure has dropped a pound below the point at which they are set, thus avoiding waste of steam. They must be set by the use of a steam-gauge.

Safety-valves should be kept clean, and should be frequently tested to see that they work freely and are correctly weighted.

BOILER FITTINGS:

STEAM-GAUGES.

IT is absolutely necessary that a boiler should be provided with a trustworthy steam-gauge for indicating the steam-pressure at any and all times.

The kind almost universally used is the dial-gauge, in which the principle of action is the tendency of a flattened curved tube, closed at one end, to become straight when subject to internal pressure, and when well made it is reliable. It was invented by M. Bourdon, but the patent has lapsed, and since then many poorly constructed and unreliable articles have been sold as Bourdon gauges.

In all metallic spring gauges the connecting pipe should have one or more bends in it, close to the gauge, filled with water, which serve to transmit the pressure, and keep the spring at a low and nearly equable temperature. In cold weather care must be taken not to let the water in the bend, or "syphon" as it is often called, freeze.

There should be suitable stop-cocks fitted on the connection-pipes of the gauges, so that communication with the boiler can be shut off for purposes of examination, etc.

Where there are several boilers in a battery, each boiler should be provided with a separate steam-gauge, which

should be connected to the boiler direct, and not with the steam-pipe.

WATER-GAUGES.

The necessity for some means of ascertaining with certainty the height of the water in the boiler at any moment is of as great importance as to have a correct steam-gauge.

The apparatus generally used for indicating the water-level are gauge-cocks and glass water-gauges.

Gauge-cocks are more generally used. There should be three cocks on each boiler, one at the highest point at which it is desired to have the water-level, and another at the lowest, and a third midway in height. These should be tried frequently, and always kept clear.

Glass water-gauges were introduced to obviate the trouble of turning the gauge-cocks by hand when wishing to know the height of water in the boiler. They consist of a glass tube, the top and bottom of which communicate by means of suitable fittings with the steam and water spaces of the boiler respectively. The level of the water in the glass is taken to be the same as that of the water in the boiler, and it is always before the eyes of the engineer or fireman. To provide for renewing, cleaning, or repacking, cocks should be arranged to shut off communication between the glass gauge and the boiler, and there should be also another cock for emptying the glass, when it is desired to drain off the water and ascertain if the gauge is working properly.

Provision should be made for clearing out the steam and water passages of the gauge when the boiler is at

work, in the event of their choking up with dirt or incrustation. Care should be taken that the water and steam passages are not too small when selecting a gauge—nothing less than one-half-inch diameter is admissible.

BLOW-OUT APPARATUS.

The bottom blow-out apparatus should be used simply for emptying the boiler—and it should be so fitted as to do this completely. It is of the greatest importance that its tightness can be depended upon, as a small amount of leakage continued for a length of time might be the cause of over-heating of the fire-sheets and the destruction of the boiler.

A plug-cock is the simplest, surest, and most durable valve that can be fitted to the blow-out pipe. If it leaks, the leak is manifest, and the position of the handle always shows whether it is shut or open.

Every boiler, in addition to the bottom blow-out apparatus, should be provided with means of blowing out water from the surface. This cannot be too strongly insisted upon, considering the serious damage done to boilers by incrustation, as the proper use of a suitable surface blow-out will greatly reduce the evils resulting therefrom.

It consists, in its simplest form, of a pan near the surface of the water, but below it, connected with a pipe passing through the boiler-shell, on which is a cock or valve for regulating the escape of the water laden with the impurities deposited in the pan. There are patented apparatus for this purpose, which are well designed, and easily fitted to a boiler.

LOW-WATER ALARM.

A thoroughly reliable low-water alarm is a valuable accessory, especially when it is fitted to indicate the rise of the water above the highest desirable level as well. There are several patented articles designed for this purpose, possessing considerable merit. Some of the associations for the inspection of boilers, in Europe, declare a suitable low-water alarm to be a necessity.

FUSIBLE PLUGS.

In some States fusible plugs are compelled by law to be inserted in boilers, under a heavy penalty. They need considerable attention to keep them in an efficient condition, as their surfaces must be kept clean and bright, and even then they are not entirely reliable.

INJECTORS.

Where no heater is used an injector really becomes a necessity, as it delivers the feed-water into the boiler at a high temperature, and thus avoids the contraction of the plates or tubes caused by cold water impinging on them. There are many different makers of these articles, and, in selecting, it is well to remember that the best is always the cheapest in the end.

PUMPS.

A steam-pump (and one fitted with a hand-motion is to be preferred) is always necessary, even when an injector is fitted. The habit prevails of having a pump of this kind many times too large for the purpose; consequently

it is difficult to run it sufficiently slow for a regular and constant feed. A smaller pump, that would allow of continuous feeding of the boiler at a fair rate of speed, is far preferable, as intermittent feed produces an irregular chilling effect on the boiler, and shortens its life.

HEATERS.

These are a most valuable adjunct to a boiler. In addition to the economy in fuel arising from its use, owing to the high temperature imparted by it to the feed-water, there is a still greater benefit obtained in the most improved varieties, viz.: the removal of the greater part of the impurities from the water before it enters the boiler, thereby preventing the formation of heavy incrustation or deposit. Again, some of these are so arranged in addition that they act as condensers, which adds still more to the economy attained by their use.

MUD-DRUMS.

These are considered indispensable in many places, but are a fruitful source of trouble. They are more liable to corrosion than any other part of a boiler, and when the feed-water is led into them, as is frequently the case, the mischief is increased, calling for frequent repairs. They serve their purpose as a collector of deposit and sediment very imperfectly. Their use cannot be recommended on any account.

STEAM-DRUMS.

These are frequently attached to boilers with the idea of increasing the steam room, and getting dryer steam; but,

unless tubes conveying gases at a high temperature are led through them, they effect very little in the way of drying the steam, and, as they are generally fitted, the increased steam room they afford is of very little value. A dry-pipe, so called, perforated on its upper side, and running nearly the whole length of the boiler, is far preferable.

REVERSE OR VACUUM VALVES.

These are valves made to open inwards — exactly the opposite to a safety-valve. They are intended to open by the pressure of the atmosphere, when the pressure in the boiler is less than atmospheric pressure, and relieve the strain. They are a useful adjunct and are easily fitted to the water-column.

GRATE-BARS.

If made of cast-iron, grate-bars should be cast in blocks of three or four bars, and made in short lengths, so that it will require about three of them in the length of the furnace. When made in this way, they weigh much less, last longer, and give a better distribution of the air to the fuel. There are many patent grate-bars; but, with the exception of revolving bars, but little can be said in their favor.

DAMPERS.

These are frequently of great use, but they should be so fitted that, when shut, there will be a space left around their outer edge to allow of the escape of gas to a moderate extent. This is especially necessary when the fires are banked.

MISCELLANEOUS ITEMS

IF the boiler is an ordinary horizontal tubular or flue boiler, in order to calculate its power, find the superficial area of the bottom half of the shell, and add to it the superficial area of all the tubes or flues (both in square feet), and divide their sum by 15; the quotient will be the horse-power.

Example.

A horizontal tubular boiler is 4 ft. in diameter and 13 ft. long, with 45 tubes 3 in. diameter and 13 ft. long. What is the horse-power?

If of 4 ft. diameter, it will have 12 ft. circumference, roughly speaking, and half of 12 ft. is 6 ft., which, multiplied by 13 ft., gives 78 sq. ft. for the area of the shell bottom.

Each tube is 3 ins. in diameter, giving, in rough numbers, 9 ins. for the circumference, or $\frac{3}{4}$ of a foot, and this, multiplied by 13 ft. gives $9\frac{3}{4}$ sq. ft. for each tube; $9\frac{3}{4}$ sq. ft. multiplied by 45 gives $438\frac{3}{4}$ sq. ft. for the surface of the tubes.

Now, adding 78 sq. ft. and $438\frac{3}{4}$ sq. ft. we have $516\frac{3}{4}$ sq. ft. as the total heating surface in the boiler (neglecting heads), and, dividing $516\frac{3}{4}$ by 15, we have $29\frac{1}{5}$ as the horse-

power; or, roughly speaking, we would rate the boiler at 30 horse-power.

TO FIND THE WEIGHT PER FOOT IN LENGTH OF ROUND-IRON.

Take the diameter in quarter inches, square it, and divide by 6.

Example.

What is the weight per foot of two-inch round-iron?

2 ins. $= 8$ quarter inches

8 squared $= 8 \times 8 = 64$

64 divided by $6 = 10\frac{2}{3}$ lbs., the required weight.

WEIGHT OF BOILER-IRON.

A cubic foot of wrought iron weighs 480 lbs., consequently a piece 1 foot square and 1 inch thick weighs $\frac{1}{12}$ of 480 lbs. or 40 lbs., and a plate 1 foot square and $\frac{1}{16}$ of an inch thick weighs $2\frac{1}{2}$ lbs.

Now from this we deduce the following rule to find the weight per sq. ft. of boiler or sheet iron:

Rule.

Multiply the thickness in sixteenths of an inch by $2\frac{1}{2}$, the result is the weight in pounds per sq. ft.

Example.

The iron in a boiler is $\frac{5}{16}$ inch thick. What is the weight per sq. ft.?

$5 \times 2\frac{1}{2} = 12\frac{1}{2}$ lbs., the weight required.

TO REPAIR A FEED OR OTHER WATER-PIPE.

Mix a stiff putty from white and red lead with boiled linseed oil, and work into it some hemp chopped into short lengths; lay it over the crack in a moderately thick mass; then wrap some strips of canvas (parceling) round the pipe tightly, overlapping both ends of the crack, and finish by serving marline over the parceling.

TO REMOVE RUST FROM IRON.

Rub the places with lard mixed with sand.

TO KEEP MACHINERY FROM RUSTING.

Take one ounce of camphor, dissolve it in one pound of melted lard, take off the scum and mix in as much fine black-lead as will give it iron color. Clean the machinery, and smear it with this mixture. After twenty-four hours rub clean with a soft linen cloth. It will keep clean for months under ordinary circumstances.

TO CLEAN SMOKY LAMP CHIMNEYS.

Put a teaspoonful of sulphuric acid in some water; tie a piece of flannel round the end of a stick, dip this in the water and draw it through the chimney. Use about four to six times as much water as acid.

TO SOLDER A BROKEN FILE.

Wet the break with muriate of zinc immediately; then heat a soldering-iron and tin the ends of the file. Heat

the file pretty warm, not enough to start the temper, but rather too warm to hold in the hand. When well tinned and hot, press the two pieces together, squeeze out all the solder, and let the file cool. Trim off the joint, and if well done, the file will break in another place the next time. Don't attempt to solder a broken file unless the break is a fresh one.

CEMENT LINING FOR CISTERNS.

Mix, 2 parts of powdered brick,
2 parts of quicklime, and
2 parts of wood-ashes.

Make into a paste with boiled linseed oil.

CEMENT TO FASTEN IRON TO STONE.

Take, 10 parts of fine iron filings,
30 parts of plaster of paris,
½ part of sal ammoniac.

Mix with weak vinegar to a fluid paste and apply at once.

BEARINGS FOR SHAFTING.

Mill-shafting ought to have bearings four diameters of the shaft in length. Bearings of that length will save oil and wearing of metal. They should be lubricated uniformly and continuously.

PLUMBER'S SOLDER.

Melt together two parts of lead and one of tin.

TO BRAZE SHEET-IRON.

Make a solution of borax and water for a flux, mix it with brass spelter and lay it thickly on the iron, and melt over a clear forge-fire; remove the work from the fire as soon as the spelter has run into the joint.

TINMAN'S SOLDER.

Melt together two parts of tin and one of lead. Use either rosin or muriate of zinc for a flux. When muriate of zinc is used, the joint, as soon as made, must be wiped with a wet rag to prevent discoloration of the tin.

TO WIPE A JOINT ON A LEAD PIPE.

Scrape the ends for about one and one-quarter inches, and paint with lamp-black and oil the part not to be soldered; rub tallow on the parts to be soldered, after scraping, for a flux. Open one end like a funnel with a wooden tampion, and cut the other end to be joined taper. Hold the ends together in position by clamps. Take several folds of canvas, well greased, in the left hand, which is held under the joint, and with a small iron ladle pour molten solder over the joint. With the pad in the left hand, catch the solder and press it on the joint; a red-hot

soldering-iron remelts it, and forms a sound joint which is finished off with the pad.

ALLOYS.

When mixing different metals, melt the one having the highest melting point first, and then add the others in the order of their melting points, heating them first to prevent their chilling the metal already melted, and stir them with a *wooden* rod. Should the metals tend to volatilize, or form an oxide, keep the surface covered with a layer of fine charcoal. Be sure and skim the surface of the melted metal carefully before pouring.

APPENDIX

WEIGHTS AND MEASURES.

TROY WEIGHT.

24 grains .... 1 pennyweight (dwt.)
20 pennyweights .... 1 ounce (oz.) = 480 grains.
12 ounces .... 1 pound (lb.) = 5760 grains (gr.)

APOTHECARIES' WEIGHT.

20 grains .... 1 scruple.
3 scruples .... 1 dram = 60 grains.
8 drams .... 1 ounce = 480 grains.
12 ounces .... 1 pound = 5760 grains.

AVOIRDUPOIS WEIGHT.

27.34375 grains .... 1 dram.
16 drams .... 1 ounce = 437½ grains.
16 ounces .... 1 pound = 7000 grains.
28 pounds .... 1 quarter (qr.)
4 quarters .... 1 hundredweight (cwt.) = 112 pounds.
20 hundredweights ... 1 ton (T.) = 2240 pounds.

U. S. LIQUID MEASURE.

4 gills .... 1 pint (pt.) = 28.875 cubic inches.
2 pints .... 1 quart (qt.) = 57.750 " "
4 quarts .... 1 gallon (gal.) = 231 " "
63 gallons .... 1 hogshead (hhd.)
2 hogsheads .... 1 pipe (p.)
2 pipes .... 1 tun.

U. S. DRY MEASURE.

2 pints...1 quart (qt.) = 67.2006 cub. inches.
4 quarts .1 gallon (gal.) = 8 pts. = 268.8025 cub. inches.
2 gallons.1 peck (pk.) = 16 pts. = 8 qts. = 537.605 cub. inches.
4 pecks ..1 bushel (bush.) = 64 pts. = 32 qts. = 8 gals. = 2150.42 cub. inches.

LONG MEASURE.

12	inches........	1 foot (ft.)
3	feet	1 yard (yd.) = 36 inches.
$5\frac{1}{2}$	yards	1 rod (rd.) = $16\frac{1}{2}$ feet.
40	rods	1 furlong (fur.) = 220 yds. = 660 ft.
8	furlongs......	1 mile (m.) = 320 rds. = 1760 yds. = 5280 ft.
3	miles.	1 league (l.) = 960 rds. = 5280 yds. = 15840 ft.

SQUARE OR LAND MEASURE.

144	square inches (sq. ins.)...	1 square foot (sq. ft.).
9	square feet	1 square yard (sq. yd.) = 1296 sq. ins.
$30\frac{1}{4}$	square yards............	1 square rod (sq. rd.) = $272\frac{1}{4}$ sq. ft.
40	square rods.........	1 rood (R.) = 1210 sq. yds. = 10890 sq. ft.
4	Roods	1 acre (A.) = 160 sq. rds. = 4840 sq. yds. = 43560 sq. ft.
640	Acres	1 square mile (sq. m.)

CUBIC OR SOLID MEASURE.

1728 cubic inches (cub. ins.)..........1 cubic or solid foot (cub. ft.)
27 cubic feet ....1 cubic or solid yard (cub. yd.)

WEIGHT OF WATER.

1	Cubic inch	.03617	pound.
12	Cubic inches	.434	pound.
1	Cubic foot (salt).............	64.3	pounds.
1	Cubic foot (fresh)	62.5	pounds.
1	Cubic foot....	7.48052	U. S. Gallons.
1.8	Cubic feet	112.0	pounds.
35.84	Cubic feet	2240	pounds.
1	Cylindrical inch.............	.02842	pound.
12	Cylindrical inches...........	.341	pound.
1	Cylindrical foot	49.10	pounds.
1	Cylindrical foot	6.0	U. S. gallons.
2.282	Cylindrical feet	112.0	pounds.
45.64	Cylindrical feet	2240	pounds.
1	Imperial Gallon	10	pounds.
11.2	Imperial Gallons	112.0	pounds.
224	Imperial Gallons............	2240	pounds.
1	U. S. Gallon	8.355	pounds.
13.44	U. S. Gallons	112.0	pounds.
268.8	U. S. Gallons	.2240	pounds.

NOTE. The center of pressure of a body of water is at two-thirds the depth from the surface.

To find the pressure in pounds per square inch of a column of water, multiply the height of the column in feet by .434. Every foot elevation is called (approximately) equal to one-half pound pressure per square inch.

MISCELLANEOUS WEIGHTS AND MEASURES.

A point = $\frac{1}{72}$ of an inch.
A line = 6 points = $\frac{1}{12}$ of an inch.
A palm = 3 inches.
A hand = 4 inches.
A span = 9 inches.
A link = 7.92 inches.
A chain = 100 links = 66 feet = 4 rods.
A fathom = 6 feet.
A cable's length = 120 fathoms = 720 feet.
An acre = 10 square chains.
A load of bricks = 500 in number.
A cord of wood = 128 cubic feet.
A cord foot = 4 ft. long × 4 ft. high × 1 ft. wide.
1 cord = 8 cord feet.

A nautical mile = 6086 feet and $\frac{7}{8}$ in. nearly

A barrel of flour = 196 pounds.

A barrel of cement = 300 pounds.

A ton of Anthracite coal (broken) = 42 cub. ft.

A ton of Bituminous coal = 47 cub. ft.

A stone = 14 pounds.

A load of lime = 32 bushels.

A load of sand = 36 bushels.

A load of unhewn timber = 40 cub. ft.

A load of squared timber = 50 cub. ft.

A load of inch boards = 600 sq. ft.

A load of 2-inch planks = 300 sq. ft.

A cubic foot of tallow = 59 lbs.

A hundred of nails = 120 in number.

A thousand of nails = 1200 in number.

A bushel of sand = 123 pounds.

A bushel of lime = 85 pounds.

A ton of coke = 95 cubic feet.

FRENCH WEIGHTS.

REDUCED TO AVOIRDUPOIS WEIGHTS OF 1 POUND = 16 OUNCES = 7000 GRAINS.

	Grains.	*Ounces.*	*Pounds.*	*Tons* (2240 lbs.)
Milligramme	0.01543316	....	....	....
Centigramme	0.1543316	....	....	......
Decigramme	1.543316	....	....	....
Gramme	15.43316	0.0352758	....	....
Decagramme	....	0.352758	0.02204737	....
Hectogramme	....	3.52758	0.2204737	....
Kilogramme	....	35.2758	2.204737	....
Myriogramme	....	....	22.04737	0.00984258
Quintal	....	....	220.4737	0.0984258
Tonneau; Millier, or Tonne	....	....	2204.737	0.984258

FRENCH MEASURES OF LENGTH.

ACCORDING TO U. S. STANDARD.

	U. S. Ins.	*U. S. Feet.*	*U. S. Yards.*	*U. S. Miles.*
Millimeter*	0.039368	0.003281	....	....
Centimeter†	0.393685	0.032807	......	....
Decimeter	3.93685	0.328071	0.109357	....
Meter‡	39.3685	3.28071	1.09357	....
Decameter	393.685	32.8071	10.9357	....
Hectometer	Road	328.071	109.357	0.0621347
Kilometer		3280.71	1093.57	0.621347
Myriameter	Measures.	32807.1	10935.7	6.21347

* Nearly the $\frac{1}{25}$ part of an inch. † Full ⅜ of an inch. ‡ Very nearly 3 feet 3⅜ inches, which is too long by only 1 part in 6062.

FRENCH SQUARE MEASURE.

ACCORDING TO U. S. STANDARD.

	U. S. Sq. Inches.	*U. S. Sq. Feet.*	*U. S. Sq. Yards.*	*U. S. Acres.*	*U. S. Miles.*
Sq. Millimeter....	0.001549	0.00001076	0.0000012	......	......
Sq. Centimeter	1.154988	0.00107631	0.0001196	.....	......
Sq. Decimeter.............	15.4988	0.10763058	0.0119589	......	.....
Sq. Meter or Centiare.....	1549.88	10.763058	1.195895	0.000247	....
Sq. Decameter or Are.....	154988.	1076.3058	119.5895	0.024709	......
Decare (not used)...	......	10763.058	1195.895	0.247086	......
Hectare............	......	107630.58	11958.95	2.47086	0.0038607
Sq. Kilometer	......	10763058.	1195895.	247.086	0.3860716
Sq. Myriameter.....	......	....	....	24708.6	38.60716

FRENCH CUBIC, OR SOLID MEASURES,

ACCORDING TO U. S. STANDARD.

Milliliter, or cubic centimeter..	cub. in. 0.0610165	Liquid, .0084525 gill. Dry, .001816 dry pint.
Centiliter	0.610165	Liquid, .084525 gill. Dry, .01816 dry pint.
Deciliter	6.10165	Liquid, .84525 gill = .21131 pint. Dry, .1816 dry pint.
Liter, or cubic decimeter	61.0165	Liquid, 1.05656 quart = 2.1131 pints. Dry, .1135 peck = .908 dry qt. = 1.816 dry pt.
Decaliter, or centistère	610.165 cub. feet. 0.353105	Liquid, 2.64141 U. S. gallons. Dry, .283742 bush. = 1.135 pks = 9.08 dry qts.
Hectoliter, or décistère	3.53105	Liquid, 26.4141 U. S. gallons. Dry, 2.83742 bushels.
Kiloliter, or cubic meter, or stère.	35.3105	Liquid, 264.141 U. S. gal.... Dry, 28.3742 bushels.... } cub. yds., 1.3078
Myrioliter or décastère......	353.105	Liquid, 2641.41 U. S. gal.... Dry, 283.742 bushels.... } cub. yds., 13.078

EQUIVALENTS OF THE DECIMAL PARTS OF A POUND (16 OUNCES) IN OUNCES.

Decimals.	*Ounces.*	*Decimals.*	*Ounces.*	*Decimals.*	*Ounces.*
0.0625	1	0.375	6.	0 6875	11
0.09375	1½	0.40625	6½	0.71875	11½
0.125	2	0.4375	7	0.75	12
0.15625	2½	0.46875	7½	0.78125	12½
0.1875	3	0.5	8	0.8125	13
0.21875	3½	0.53125	8½	0.84375	13½
0.25	4	0.5625	9	0.875	14
0.28125	4½	0.59375	9½	0.90625	14½
0.3125	5	0.625	10	0.9375	15
0 34375	5½	0.65625	10½	0.96875	15½

WEIGHT OF CAST-IRON BALLS,

FROM 1 INCH TO 12 INCHES DIAMETER.

Diameter.	*Weight.*	*Diameter.*	*Weight.*	*Diameter.*	*Weight.*	*Diameter.*	*Weight.*	*Diameter.*	*Weight.*
In.	Lbs.	In.	Lbs.	In.	Lbs.	In.	Lbs.	In.	Lbs.
1	0.136	3½	5.84	6	29.45	8½	83.73	11	181.48
1½	0.460	4	8.72	6½	37.44	9	99.4	11½	207.37
2	1.09	4½	12.42	7	46.76	9½	116.9	12	235.62
2½	2.13	5	17.04	7½	57.52	10	136.35		
3	3.68	5½	22.68	8	69.81	10½	157.84		

EQUIVALENTS OF THE DECIMAL PARTS OF A FOOT IN INCHES.

Decimal value in feet.	*Fractions of a foot in inches.*	*Decimal value in feet.*	*Fractions of a foot in inches.*	*Decimal value in feet.*	*Fractions of a foot in inches.*
.01041	⅛	.07291	⅞	.5	6
.02083	¼	.0833	1	.5833	7
.03125	⅜	.1666	2	.6666	8
.04166	½	.25	3	.75	9
.05208	⅝	.3333	4	.8333	10
.0625	¾	.4166	5	.9166	11

DECIMAL EQUIVALENTS OF FRACTIONS OF AN INCH.

Fractions of an inch.	*Decimal value.*	*Fractions of an inch.*	*Decimal value.*	*Fractions of an inch.*	*Decimal value.*
$\frac{1}{64}$	.015625	$\frac{11}{32}$	.34375	$\frac{11}{16}$	.6875
$\frac{1}{32}$	.03125	$\frac{3}{8}$	.375	$\frac{23}{32}$	.71875
$\frac{1}{16}$	.0625	$\frac{13}{32}$	.40625	$\frac{3}{4}$	.75
$\frac{3}{32}$	.09375	$\frac{7}{16}$	.4375	$\frac{25}{32}$	.78125
$\frac{1}{8}$	.125	$\frac{15}{32}$	.46875	$\frac{13}{16}$	.8125
$\frac{5}{32}$	.15625	$\frac{1}{2}$	.5	$\frac{27}{32}$	.84375
$\frac{3}{16}$	.1875	$\frac{17}{32}$	.53125	$\frac{7}{8}$	.875
$\frac{7}{32}$	.21875	$\frac{9}{16}$	.5625	$\frac{29}{32}$	.90625
$\frac{1}{4}$	.25	$\frac{19}{32}$	59375	$\frac{15}{16}$	.9375
$\frac{9}{32}$	.28125	$\frac{5}{8}$	.625	$\frac{31}{32}$	.96875
$\frac{5}{16}$	.3125	$\frac{21}{32}$	.65625		

WEIGHT OF A LINEAL FOOT OF FLAT, BAR, AND HOOP IRON IN POUNDS.

Thickness in Inches.	BREADTH IN INCHES.										
	3½	3	2¾	2½	2¼	2	1¾	1½	1¼	1	¾
⅛	1.47	1.26	1.15	1.05	.094	.084	.073	.063	.052	.042	.031
3-16	2.20	1.89	1.73	1.57	1.41	1.26	1.10	.094	.078	.063	.047
¼	2.94	2.52	2.31	2.10	1.89	1.68	1.47	1.26	1.05	.084	.063
⅜	4.41	3.78	3.46	3.15	2.83	2.52	2.20	1.89	1.57	1.26	.094
½	5.88	5.04	4.62	4.20	3.78	3.36	2.94	2.22	2.10	1.68	1.26
⅝	7.35	6.30	5.77	5.25	4.72	4.20	3.67	3.15	2.62	2.10	1.57
¾	8.82	7.56	6.93	6.30	5.66	5.04	4.41	3.78	3.15	2.52	
⅞	10.29	8.82	8.08	7.35	6.61	5.88	5.14	4.41	3.67	2.94	
1 in.	11.76	10.08	9.24	8.40	7.56	6.72	5.87	5.04	4.20		

WEIGHT OF A SQUARE FOOT OF PLATE IRON IN POUNDS.

Thickness in parts of an inch.......	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$
Weight in pounds....	5	7½	10	12½	15	17½	20	22½	25	27½	30

WEIGHT OF A SQUARE FOOT OF SHEET IRON IN POUNDS.

Number on wire gauge.........	1	2	3	4	5	6	7	8	9	10	11
And weight in pounds.......	12.5	12	11	10	9	8	7.5	7	6	5.68	5
Number on wire gauge.........	12	13	14	15	16	17	18	19	20	21	22
And weight in pounds.......	4.62	4.32	4	3.95	3	2.5	2.18	1.93	1.62	1.5	1.37

WEIGHT OF A SQUARE FOOT OF SHEET AND PLATE COPPER IN POUNDS.

Number on wire gauge	12	13	14	15	16	17	18	19	20	21	22
And weight in pounds.	5.08	4.34	3.60	3.27	2.90	2.52	2.15	1.97	1.78	1.62	1.45
Thickness in parts of an inch	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{5}{16}$	$\frac{11}{32}$	$\frac{3}{8}$	$\frac{13}{32}$	$\frac{7}{16}$	$\frac{1}{2}$
Weight in pounds....	7.26	8.71	10.16	11.61	13.07	14.52	15.97	17.41	18.87	20.32	23.22

NUMBER OF U. S. GALLONS (231 CUBIC INCHES) IN 1 FOOT LENGTH OF PIPE OF DIFFERENT DIAMETERS.

Diam. in inches.	*Gallons.*	*Diam. in inches.*	*Gallons.*	*Diam. in inches.*	*Gallons.*
¾	.0230	3½	.5000	10	4.081
1	.0408	4	.6528	11	4.937
1¼	.0638	4½	.8263	12	5.876
1½	.0918	5	1.020	13	6.895
1¾	.1250	6	1.469	14	7.997
2	.1632	7	1.999	15	9.180
2½	.2550	8	2.611	16	10.44
3	.3673	9	3.305	18	13.22

NUMBER OF U. S. GALLONS (231 CUBIC INCHES) CONTAINED IN CIRCULAR TANKS.

Depth in feet.	1	2	3	4	5	6	7	8	9	10	*Depth in feet.*
Diam.	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Diam.*
Inches.											Inches.
20	16.32	32.64	48.96	65.28	81.60	97.92	114.24	130.56	146.88	163.20	20
24	23.50	47.00	70.50	94.00	117.50	141.00	164.50	188.00	211.50	235.00	24
26	27.58	55.16	82.74	110.32	137.90	165.48	193.06	220.64	248.22	275.80	26
28	31.99	63.98	95.97	127.96	159.95	191.94	223.93	255.92	288.91	319.90	28
30	36.72	73.44	110.16	146.88	183.60	220.32	257.04	293.76	330.48	367.20	30
36	52.88	105.76	158.64	211.52	264.40	317.28	370.16	423.04	475.92	528.80	36
42	71.96	143.92	215.88	287.84	359.80	431.76	503.72	575.68	647.64	719.60	42
45	82.62	165.24	247.86	330.48	413.10	495.72	578.34	660.96	743.58	826.20	45
48	94.02	188.04	282.06	376.08	470.10	564.12	658.14	752.16	846.18	940.20	48
50	102.00	204.00	306.00	408.00	510.00	612.0	714.0	816.0	918.0	1020.0	50
54	119.0	238.00	357.00	476.00	595.00	714.0	833.0	952.0	1071.0	1190.0	54
60	146.9	293.8	440.70	587.6	734.5	881.4	1028.3	1175.2	1322.1	1469.0	60
66	177.7	355.4	533.10	710.8	888.5	1066.2	1243.9	1421.6	1599.2	1777.0	66
72	211.5	423 0	634.50	846.0	1057.5	1269.0	1480.5	1692.0	1903.5	2115.0	72
84	287.8	575.6	863.4	1151.2	1439.0	1726.8	2014.6	2302.4	2590.2	2878.0	84

CONTENTS OF CIRCULAR TANKS IN U. S. GALLONS (231 CUBIC INCHES).

Depth.	8	9	10	11	12	13	14	15	16	17	18	19	20
Diam.	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*
10	4,354	4,898	5,442	5,986	6,531	7,075	7,619	8,163	8,707	9,252	9,796	10,340	10,884
12	6,767	7,614	8,460	9,306	10,152	10,998	11,844	12,690	13,536	14,382	15,228	16,074	16,920
14	9,212	10,363	11,515	12,666	13,818	14,969	16,121	17,273	18,424	19,576	20,726	21,878	23,030
16	12,032	13,535	15,040	16,544	18,048	19,552	21,056	22,560	24,064	25,568	27,070	28,575	30,080
18	15,228	17,132	19,034	20,939	22,842	24,746	26,649	28,553	30,456	32,360	34,264	36,166	38,068
20	18,800	21,150	23,499	25,850	28,200	30,550	32,901	35,251	37,601	39,951	42,300	44,649	46,998
22	22,748	25,592	28,435	31,277	31,279	34,123	36,966	39,810	42,653	45,497	51,184	54,027	56,870
24	27,068	30,456	33,841	37,225	40,607	43,993	47,377	50,761	54,145	57,529	60,912	64,297	67,682
26	31,772	35,744	39,716	43,687	47,659	51,628	55,602	59,574	63,545	67,517	71,488	77,460	79,432
28	36,849	41,452	46,061	50,667	55,273	59,879	64,481	69,092	73,698	78,304	82,904	87,513	92,122
30	42,301	47,588	52,876	58,164	63,451	68,739	74,027	79,310	84,602	89,890	95,176	100,464	105,752
32	48,129	54,140	60,161	66,178	72,194	78,210	84,226	90,242	96,253	102,275	108,280	114,301	120,322
34	54,333	61,125	67,917	74,708	81,500	88,292	95,083	101,875	108,667	115,451	122,250	129,042	135,834
36	60,915	68,530	76,144	83,758	91,373	98,987	106,602	114,216	121,831	129,445	137,059	144,674	152,288
38	67,870	76,354	84,838	93,321	101,805	110,289	118,773	127,257	135,740	144,224	152,708	161,192	169,675
40	75,202	84,603	94,003	103,403	112,804	122,204	131,604	141,005	150,405	159,805	169,205	178,606	188,006

Depths and Diameters are both in feet. 1 cubic foot = 7.8405 gallons.

SHRINKAGE OF CASTINGS.

Iron, small cylinders	$= \frac{1}{16}$ inch per foot.
" pipes	$= \frac{1}{8}$ inch per foot.
" girders, beams, etc	$= \frac{1}{8}$ inch in 15 inches.
" large cylinders, the contraction of diameter at top	$= \frac{1}{16}$ inch per foot.
" large cylinders, the contraction of diameter at bottom	$= \frac{1}{12}$ inch per foot.
" large cylinders, contraction in length	$= \frac{1}{8}$ inch in 16 inches.
Brass, thin	$= \frac{1}{8}$ inch in 9 inches.
Brass, thick	$= \frac{1}{8}$ inch in 10 inches.
Zinc	$= \frac{5}{16}$ inch in a foot.
Lead	$= \frac{5}{16}$ inch in a foot.
Copper	$= \frac{3}{16}$ inch in a foot.
Bismuth	$= \frac{5}{32}$ inch in a foot.

MELTING POINTS OF METALS AND SOLIDS.

	Fahr.		*Fahr.*
Antimony melts at	951°	Platinum melts at	4580°
Bismuth "	476°	Potassium "	135°
Brass "	1900°	Saltpeter "	600°
Cadmium "	602°	Steel "	2500°
Cast Iron "	3479°	Sulphur "	225°
Copper "	2548°	Silver "	1250°
Glass "	2377°	Tin "	420°
Gold "	2590°	Wrought Iron "	3982°
Lead "	594°	Zinc "	740°
Ice "	32°	Aluminum "	700°

BOILING POINTS.

	Fahr.		*Fahr.*
Ether	100°	Naphtha	186°
Fresh Water	212°	Oil of Turpentine	304°
Linseed Oil	640°	Salt Water	213.2°
Mercury	662°	Sweet Oil	412°

LINEAR EXPANSION OF STEAM PIPES.

100 FEET OF BRASS PIPE LENGTHENS .0125 INCHES FOR 1° FAHR. 100 FEET OF WROUGHT-IRON PIPE LENGTHENS .008 INCHES FOR 1° FAHR.

Steam pressure by gauge.	*Linear increase for 100 feet in length of pipe.*		*Corresponding Temperature in degrees.*
	Wrought iron.	*Brass.*	
Pounds	Inches.	Inches.	Fahr.
Boiling Water.	$1\frac{3}{16}$	$1\frac{7}{8}$	212°
5	$1\frac{11}{32}$	$2\frac{3}{32}$	228°
10	$1\frac{7}{16}$	$2\frac{1}{4}$	240°
15	$1\frac{1}{2}$	$2\frac{3}{8}$	250°
25	$1\frac{21}{32}$	$2\frac{9}{16}$	267°
30	$1\frac{3}{4}$	$2\frac{11}{16}$	275°
40	$1\frac{13}{16}$	$2\frac{13}{16}$	287°
50	$1\frac{7}{8}$	$2\frac{31}{32}$	298°
60	$1\frac{31}{32}$	$3\frac{3}{32}$	307°
70	$2\frac{1}{16}$	$3\frac{3}{16}$	316°
80	$2\frac{1}{8}$	$3\frac{5}{16}$	324°
90	$2\frac{3}{16}$	$3\frac{3}{8}$	331°
100	$2\frac{7}{32}$	$3\frac{15}{32}$	338°
125	$2\frac{9}{32}$	$3\frac{9}{16}$	344°
150	$2\frac{7}{16}$	$3\frac{13}{16}$	366°
175	$2\frac{17}{32}$	$3\frac{31}{32}$	377°

RELATIVE VALUE OF NON-CONDUCTORS.

(C. E. EMERY.)

Non-Conductors.	*Value.*
Wool Felt	1.000
Mineral Wool, No. 2	.832
" " with Tar	.715
Sawdust	.680
Mineral Wool, No. 1	.676
Charcoal	.632
Pine-wood, across fiber	.553
Loam, dry and open	.550
Slacked Lime	.480
Gas-house Carbon	.470
Asbestos	.363
Coal Ashes	.345
Coke, in lumps	.277
Air Space, undivided	.186

IGNITION POINTS OF VARIOUS SUBSTANCES.

Phosphorus ignites at	150°	Fahr.
Sulphur " "	500°	"
Wood " "	800°	"
Coal " "	1000°	"
Lignite, in the form of dust, ignites at	150°	"
Cannel Coal, " " "	200°	"
Coking Coal, " " "	250°	"
Anthracite, " " "	300°	"

TABLE OF THE STRONGEST FORM AND PROPORTION OF RIVETED JOINTS.

Thickness of Plate.	*Diameter of Rivet.*	*Length of Rivet.*	*Pitch.*	*Lap.*
$\frac{3}{16}$ inch.	$\frac{3}{8}$ inch.	0.85 inches.	1.14 inches.	1.14 inches.
$\frac{1}{4}$ "	$\frac{1}{2}$ "	1.12 "	1.5 "	1.5 "
$\frac{5}{16}$ "	$\frac{5}{8}$ "	1.39 "	1.55 "	1.76 "
$\frac{3}{8}$ "	$\frac{3}{4}$ "	1.68 "	1.87 "	2.1 "
$\frac{1}{2}$ "	$\frac{7}{8}$ "	2.25 "	2.00 "	2.25 "
$\frac{5}{8}$ "	1 "	2.82 "	2.5 "	2.82 "
$\frac{3}{4}$ "	$1\frac{1}{8}$ "	3.37 "	3.0 "	3.37 '

DEPRECIATION OF MACHINERY.

Per annum on first cost.	*Depreciation.*	*Wear and tear.*	*Total.*
Engines	6	3	*9
Boilers	10	3	*13
Machine Tools	7½	3½	*11
Mill-work Shafting and Gear	4	2½	6½
Bands and Belts	—	45	45

* This is too high, probably, as the author's experience and that of many of his acquaintance would not warrant more than 6 per cent. depreciation per annum.

WEIGHT OF A LINEAL FOOT OF FLAT, BAR, AND HOOP IRON IN POUNDS.

Thickness in Inches.	BREADTH IN INCHES.										
	3½	3	2¾	2½	2¼	2	1¾	1½	1¼	1	¾
⅛	1.47	1.26	1.15	1.05	.094	.084	.073	.063	.052	.042	.031
3-16	2.20	1.89	1.73	1.57	1.41	1.26	1.10	.094	.078	.063	.047
¼	2.94	2.52	2.31	2.10	1.89	1.68	1.47	1.26	1.05	.084	.063
⅜	4.41	3.78	3.46	3.15	2.83	2.52	2.20	1.89	1.57	1.26	.094
½	5.88	5.04	4.62	4.20	3.78	3.36	2.94	2.22	2.10	1.68	1.26
⅝	7.35	6.30	5.77	5.25	4.72	4.20	3.67	3.15	2.62	2.10	1.57
¾	8.82	7.56	6.93	6.30	5.66	5.04	4.41	3.78	3.15	2.52	
⅞	10.29	8.82	8.08	7.35	6.61	5.88	5.14	4.41	3.67	2.94	
1 in.	11.76	10.08	9.24	8.40	7.56	6.72	5.87	5.04	4.20		

WEIGHT OF A SQUARE FOOT OF PLATE IRON IN POUNDS.

Thickness in parts of an inch.......	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$
Weight in pounds....	5	7½	10	12½	15	17½	20	22½	25	27½	30

WEIGHT OF A SQUARE FOOT OF SHEET IRON IN POUNDS.

Number on wire gauge.........	1	2	3	4	5	6	7	8	9	10	11
And weight in pounds.......	12.5	12	11	10	9	8	7.5	7	6	5.68	5
Number on wire gauge.........	12	13	14	15	16	17	18	19	20	21	22
And weight in pounds.......	4.62	4.32	4	3.95	3	2.5	2.18	1.93	1.62	1.5	1.37

WEIGHT OF A SQUARE FOOT OF SHEET AND PLATE COPPER IN POUNDS.

Number on wire gauge	12	13	14	15	16	17	18	19	20	21	22
And weight in pounds.	5.08	4.34	3.60	3.27	2.90	2.52	2.15	1.97	1.78	1.62	1.45
Thickness in parts of an inch	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{5}{16}$	$\frac{11}{32}$	$\frac{3}{8}$	$\frac{13}{32}$	$\frac{7}{16}$	$\frac{1}{2}$
Weight in pounds....	7.26	8.71	10.16	11.61	13.07	14.52	15.97	17.41	18.87	20.32	23.22

NUMBER OF U. S. GALLONS (231 CUBIC INCHES) IN 1 FOOT LENGTH OF PIPE OF DIFFERENT DIAMETERS.

Diam. in inches.	*Gallons.*	*Diam. in inches.*	*Gallons.*	*Diam. in inches.*	*Gallons.*
¾	.0230	3½	.5000	10	4.081
1	.0408	4	.6528	11	4.937
1¼	.0638	4½	.8263	12	5.876
1½	.0918	5	1.020	13	6.895
1¾	.1250	6	1.469	14	7.997
2	.1632	7	1.999	15	9.180
2½	.2550	8	2.611	16	10.44
3	.3673	9	3.305	18	13.22

NUMBER OF U. S. GALLONS (231 CUBIC INCHES) CONTAINED IN CIRCULAR TANKS.

Depth in feet.	1	2	3	4	5	6	7	8	9	10	*Depth in feet.*
Diam.	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Diam.*
Inches.											Inches.
20	16.32	32.64	48.96	65.28	81.60	97.92	114.24	130.56	146.88	163.20	20
24	23.50	47.00	70.50	94.00	117.50	141.00	164.50	188.00	211.50	235.00	24
26	27.58	55.16	82.74	110.32	137.90	165.48	193.06	220.64	248.22	275.80	26
28	31.99	63.98	95.97	127.96	159.95	191.94	223.93	255.92	288.91	319.90	28
30	36.72	73.44	110.16	146.88	183.60	220.32	257.04	293.76	330.48	367.20	30
36	52.88	105.76	158.64	211.52	264.40	317.28	370.16	423.04	475.92	528.80	36
42	71.96	143.92	215.88	287.84	359.80	431.76	503.72	575.68	647.64	719.60	42
45	82.62	165.24	247.86	330.48	413.10	495.72	578.34	660.96	743.58	826.20	45
48	94.02	188.04	282.06	376.08	470.10	564.12	658.14	752.16	846.18	940.20	48
50	102.00	204.00	306.00	408.00	510.00	612.0	714.0	816.0	918.0	1020.0	50
54	119.0	238.00	357.00	476.00	595.00	714.0	833.0	952.0	1071.0	1190.0	54
60	146.9	293.8	440.70	587.6	734.5	881.4	1028.3	1175.2	1322.1	1469.0	60
66	177.7	355.4	533.10	710.8	888.5	1066.2	1243.9	1421.6	1599.2	1777.0	66
72	211.5	423.0	634.50	846.0	1057.5	1269.0	1480.5	1692.0	1903.5	2115.0	72
84	287.8	575.6	863.4	1151.2	1439.0	1726.8	2014.6	2302.4	2590.2	2878.0	84

CONTENTS OF CIRCULAR TANKS IN U. S. GALLONS (231 CUBIC INCHES).

Depth.	8	9	10	11	12	13	14	15	16	17	18	19	20
Diam.	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*
10	4,354	4,898	5,442	5,986	6,531	7,075	7,619	8,163	8,707	9,252	9,796	10,340	10,884
12	6,767	7,614	8,460	9,306	10,152	10,998	11,844	12,690	13,536	14,382	15,228	16,074	16,920
14	9,212	10,363	11,515	12,666	13,818	14,969	16,121	17,273	18,424	19,576	20,726	21,878	23,030
16	12,032	13,535	15,040	16,544	18,048	19,552	21,056	22,560	24,064	25,568	27,070	28,575	30,080
18	15,228	17,132	19,034	20,939	22,842	24,746	26,649	28,553	30,456	32,360	34,264	36,166	38,068
20	18,800	21,150	23,499	25,850	28,200	30,550	32,901	35,251	37,601	39,951	42,300	44,649	46,998
22	22,748	25,592	28,435	31,277	31,279	34,123	36,966	39,810	42,653	45,497	51,184	54,027	56,870
24	27,068	30,456	33,841	37,225	40,607	43,993	47,377	50,761	54,145	57,529	60,912	64,297	67,682
26	31,772	35,744	39,716	43,687	47,659	51,628	55,602	59,574	63,545	67,517	71,488	77,460	79,432
28	36,849	41,452	46,061	50,667	55,273	59,879	64,481	69,092	73,698	78,304	82,904	87,513	92,122
30	42,301	47,588	52,876	58,164	63,451	68,739	74,027	79,310	84,602	89,890	95,176	100,464	105,752
32	48,129	54,140	60,161	66,178	72,194	78,210	84,226	90,242	96,253	102,275	108,280	114,301	120,322
34	54,333	61,125	67,917	74,708	81,500	88,292	95,083	101,875	108,667	115,451	122,250	129,042	135,834
36	60,915	68,530	76,144	83,758	91,373	98,987	106,602	114,216	121,831	129,445	137,059	144,674	152,288
38	67,870	76,354	84,838	93,321	101,805	110,289	118,773	127,257	135,740	144,224	152,708	161,192	169,675
40	75,202	84,603	94,003	103,403	112,804	122,204	131,604	141,005	150,405	159,805	169,205	178,606	188,006

Depths and Diameters are both in feet. 1 cubic foot = 7.8405 gallons.

PROPORTIONS, HEATING SURFACE, AND HORSE-POWER OF BOILERS FITTED WITH $3\frac{1}{2}$-INCH TUBES.

SHELL.		*Number of Tubes.*	*Heating surface $\frac{2}{3}$ shell and whole of tubes.*	*Horse power at 15 feet.*
Diameter.	*Length.*			
Inches.	Feet.		Square Feet.	
44	12	32	444	29.6
	14	32	519	34.6
	16	32	592	39.5
	18	32	666	44.4
46	12	34	470	31.3
	14	34	548	37.2
	16	34	626	41.7
	18	34	706	47.1
48	12	36	497	33.1
	14	36	579	38.6
	16	36	662	44.1
	18	36	745	49.7
52	12	48	637	42.5
	14	48	743	49.5
	16	48	849	56.6
	18	48	955	63.7
54	12	48	640	42.7
	14	48	747	49.8
	16	48	855	57.0
	18	48	962	64.1
56	12	55	722	48.1
	14	55	843	56.2
	16	55	962	64.1
	18	55	1083	72.2
60	16	62	1048	69.9
	18	62	1178	78.5

PROPORTIONS, HEATING SURFACE, AND HORSE-POWER OF BOILERS FITTED WITH 4-INCH TUBES.

SHELL.		*Number of tubes.*	*Heating surface ⅔ shell and whole of tubes.*	*Horse power at 15 feet.*
Diameter.	*Length.*			
Inches.	Feet.		Square Feet.	
48	12	26	428	28.5
	14	26	498	33.2
	16	26	570	38.0
	18	26	641	42.7
50	12	30	482	32.1
	14	30	562	37.5
	16	30	643	42.9
	18	30	722	48.1
52	12	32	511	34.1
	14	32	596	39.7
	16	32	681	45.4
	18	32	766	51.1
54	12	36	565	37.7
	14	36	660	44.0
	16	36	754	50.3
	18	36	849	56.6
56	12	41	632	42.1
	14	41	738	49.2
	16	41	843	56.2
	18	41	949	63.3
58	12	45	686	45.7
	14	45	802	53.5
	16	45	916	61.1
	18	45	1030	68.7
60	12	46	704	46.9
	14	46	821	54.7
	16	46	939	62.6
	18	46	1055	70.3
66	20	56	1410	94.0

CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam.	*Circum.*	*Area.*	*Diam.*	*Circum.*	*Area.*	*Diam.*	*Circum.*	*Area.*
Ins.	Ins.	Sq. ins.	Ins.	Ins.	Sq. ins.	Ins.	Ins.	Sq. ins.
1/16	.19635	.00307	3 ins.	9.4248	7.0686	6 ins.	18.849	28.274
1/8	.3927	.0122	1/8	9.8175	7.6699	1/8	19.242	29.464
1/4	.7854	.0490	1/4	10.210	8.2957	1/4	19.635	30.679
3/8	1.1781	.1104	3/8	10.602	8.9462	3/8	20.027	31.919
1/2	1.5708	.1963	1/2	10.995	9.6211	1/2	20.420	33.183
5/8	1.9635	.3068	5/8	11.388	10.320	5/8	20.813	34.471
3/4	2.3562	.4417	3/4	11.781	11.044	3/4	21.205	35.784
7/8	2.7489	.6013	7/8	12.173	11.793	7/8	21.598	37.122
1 in.	3.1416	.7854	4 ins.	12.566	12.566	7 ins.	21.991	38.484
1/8	3.5343	.9940	1/8	12.959	13.364	1/8	22.383	39.871
1/4	3.9270	1.2271	1/4	13.351	14.186	1/4	22.776	41.282
3/8	4.3197	1.4848	3/8	13.744	15.033	3/8	23.169	42.718
1/2	4.7124	1.7671	1/2	14.137	15.904	1/2	23.562	44.178
5/8	5.1051	2.0739	5/8	14.529	16.800	5/8	23.954	45.663
3/4	5.4978	2.4052	3/4	14.922	17.720	3/4	24.347	47.173
7/8	5.8905	2.7611	7/8	15.315	18.665	7/8	24.740	48.707
2 ins.	6.2832	3.1416	5 ins.	15.708	19.635	8 ins.	25.132	50.265
1/8	6.6759	3.5465	1/8	16.100	20.629	1/8	25.515	51.848
1/4	7.0686	3.9760	1/4	16.493	21.647	1/4	25.918	53.456
3/8	7.4613	4.4302	3/8	16.886	22.690	3/8	26.310	55.088
1/2	7.8540	4.9087	1/2	17.278	23.758	1/2	26.703	56.745
5/8	8.2467	5.4119	5/8	17.671	24.850	5/8	27.096	58.426
3/4	8.6394	5.9395	3/4	18.064	25.967	3/4	27.489	60.132
7/8	9.0321	6.4918	7/8	18.457	27.108	7/8	27.881	61.862

CIRCUMFERENCES AND AREAS OF CIRCLES.—*Continued.*

Diam.	*Circum.*	*Area.*	*Diam.*	*Circum.*	*Area.*	*Diam.*	*Circum.*	*Area.*
Ins.	Ins.	Sq. ins.	Ins.	Ins.	Sq. Ins.	Ins.	Ins.	Sq. Ins.
9 ins.	28.274	63.617	12 ins.	37.699	113.097	15 ins.	47.124	176.715
⅛	28.667	65.396	⅛	38.091	115.466	⅛	47.516	179.672
¼	29.059	67.200	¼	38.484	117.859	¼	47.909	182.654
⅜	29.452	69.029	⅜	38.877	120.276	⅜	48.302	185.661
½	29.845	70.882	½	39.270	122.718	½	48.694	188.692
⅝	30.237	72.759	⅝	39.662	125.184	⅝	49.087	191.748
¾	30.630	74.662	¾	40.055	127.676	¾	49.480	194.828
⅞	31.023	76.588	⅞	40.448	130.192	⅞	49.872	197.933
10 ins.	31.416	78.540	13 ins.	40.840	132.732	16 ins.	50.265	201.062
⅛	31.808	80.515	⅛	41.233	135.297	⅛	50.658	204.216
¼	32.201	82.516	¼	41.626	137.886	¼	51.051	207.394
⅜	32.594	84.540	⅜	42.018	140.500	⅜	51.443	210.597
½	32.986	86.590	½	42.411	143.139	½	51.836	213.825
⅝	33.379	88.664	⅝	42.804	145.802	⅝	52.229	217.077
¾	33.772	90.762	¾	43.197	148.489	¾	52.621	220.353
⅞	34.164	92.885	⅞	43.589	151.201	⅞	53.014	223.654
11 ins.	34.557	95.033	14 ins.	43.982	153.938	17 ins.	53.407	226.980
⅛	34.950	97.205	⅛	44.375	156.699	⅛	53.799	230.330
¼	35.343	99.402	¼	44.767	159.485	¼	54.192	233.705
⅜	35.735	101.623	⅜	45.160	162.295	⅜	54.585	237.104
½	36.128	103.869	½	45.553	165.130	½	54.978	240.528
⅝	36.521	106.139	⅝	45.945	167.989	⅝	55.370	243.977
¾	36.913	108.434	¾	46.338	170.873	¾	55.763	247.450
⅞	37.306	110.753	⅞	46.731	173.782	⅞	56.156	250.947

CIRCUMFERENCES AND AREAS OF CIRCLES.—*Continued.*

Diam.	*Circum.*	*Area.*	*Diam.*	*Circum.*	*Area.*	*Diam.*	*Circum.*	*Area.*
Ins.	Ins.	Sq. ins.	Ins.	Ins.	Sq. ins.	Ins.	Ins.	Sq. ins.
18 ins.	56.548	254.469	21 ins.	65.973	346.361	24 ins.	75.398	452.390
⅛	56.941	258.016	⅛	66.366	350.497	⅛	75.791	457.115
¼	57.334	261.587	¼	66.759	354.657	¼	76.183	461.864
⅜	57.726	265.182	⅜	67.151	358.841	⅜	76.576	466.638
½	58.119	268.803	½	67.544	363.051	½	76.969	471.436
⅝	58.512	272.447	⅝	67.937	367.284	⅝	77.361	476.259
¾	58.905	276.117	¾	68.329	371.543	¾	77.754	481.106
⅞	59.297	279.811	⅞	68.722	375.826	⅞	78.147	485.978
19 ins.	59.690	283.529	22 ins.	69.115	380.133	25 ins.	78.540	490.875
⅛	60.083	287.272	⅛	69.507	384.465	⅛	78.932	495.796
¼	60.475	291.039	¼	69.900	388.822	¼	79.325	500.741
⅜	60.868	294.831	⅜	70.293	393.203	⅜	79.718	505.711
½	61.261	298.648	½	70.686	397.608	½	80.110	510.706
⅝	61.663	302.489	⅝	71.078	402.038	⅝	80.503	515.725
¾	62.046	306.355	¾	71.471	406.493	¾	80.896	520.769
⅞	62.439	310.245	⅞	71.864	410.972	⅞	81.288	525.837
20 ins.	62.832	314.160	23 ins.	72.256	415.476	26 ins.	81.681	530.930
⅛	63.224	318.099	⅛	72.649	420.004	⅛	82.074	536.047
¼	63.617	322.063	¼	73.042	424.557	¼	82.467	541.189
⅜	64.010	326.051	⅜	73.434	429.135	⅜	82.859	546.356
½	64.402	330.064	½	73.827	433.731	½	83.252	551.547
⅝	64.795	334.101	⅝	74.220	438.363	⅝	83.645	556.762
¾	65.188	338.163	¾	74.613	443.014	¾	84.037	562.002
⅞	65.580	342.250	⅞	75.005	447.699	⅞	84.430	567.267

CIRCUMFERENCES AND AREAS OF CIRCLES.—*Continued.*

Diam.	*Circum.*	*Area.*	*Diam.*	*Circum.*	*Area.*	*Diam.*	*Circum.*	*Area.*
Ins.	Ins.	Sq. ins.	Ins.	Ins.	Sq. ins.	Ins.	Ins.	Sq. ins.
27 ins.	84.823	572.556	30 ins.	94.248	706.860	33 ins.	103.672	855.30
⅛	85.215	577.870	⅛	94.640	712.762	⅛	104.055	861.79
¼	85.608	583.208	¼	95.033	718.690	¼	104.458	868.30
⅜	86.001	588.571	⅜	95.426	724.641	⅜	104.850	874.84
½	86.394	593.958	½	95.818	730.618	½	105.243	881.41
⅝	86.786	599.370	⅝	96.211	736.619	⅝	105.636	888.00
¾	87.179	604.807	¾	96.604	742.644	¾	106.029	894.61
⅞	87.572	610.268	⅞	96.996	748.694	⅞	106.421	901.25
28 ins.	87.964	615.753	31 ins.	97.389	754.769	34 ins.	106.814	907.92
⅛	88.357	621.263	⅛	97.782	760.868	⅛	107.207	914.61
¼	88.750	626.798	¼	98.175	766.992	¼	107.599	921.32
⅜	89.142	632.357	⅜	98.567	773.140	⅜	107.992	928.06
½	89.535	637.941	½	98.968	779.313	½	108.385	934.82
⅝	89.928	643.594	⅝	99.353	785.510	⅝	108.777	941.60
¾	90.321	649.182	¾	99.745	791.732	¾	109.170	948.41
⅞	90.713	654.839	⅞	100.138	797.978	⅞	109 563	955.25
29 ins.	91.106	660.521	32 ins.	100.531	804.249	35 ins.	109.956	962.11
⅛	91.499	666.277	⅛	100.924	810.545	⅛	110.348	968.99
¼	91.891	671.958	¼	101.316	816.865	¼	110.741	975.90
⅜	92.284	677.714	⅜	101.709	823.209	⅜	111.134	982.84
½	92.677	683.494	½	102.102	829.578	½	111.526	989.80
⅝	93.069	689.298	⅝	102.494	835.972	⅝	111.919	996.78
¾	93.462	695.128	¾	102.887	842.390	¾	112.312	1003.78
⅞	93.855	700.981	⅞	103.280	848.833	⅞	112.704	1010.82

CIRCUMFERENCES AND AREA OF CIRCLES.—*Continued.*

Diam.	*Circum.*	*Area.*	*Diam.*	*Circum.*	*Area.*	*Diam.*	*Circum.*	*Area.*
Ins.	Ins.	Sq. Ins.	Ins.	Ins.	Sq. Ins.	Ins.	Ins.	Sq. Ins.
36 ins.	113.097	1017.87	39 ins.	122.522	1194.59	42 ins.	131.947	1385.44
⅛	113.490	1024.95	⅛	122.915	1202.26	⅛	132.339	1393.70
¼	113.883	1032.06	¼	123.307	1209.95	¼	132.732	1401.98
⅜	114.275	1039.19	⅜	123.700	1217.67	⅜	133.125	1410.29
½	114.668	1046.35	½	124.093	1225.42	½	133.518	1418.62
⅝	115.061	1053.52	⅝	124.485	1233.18	⅝	133.910	1426.98
¾	115.453	1060.73	¾	124.878	1240.98	¾	134.303	1435.36
⅞	115.846	1067.95	⅞	125.271	1248.79	⅞	134.696	1443.77
37 ins.	116.239	1075.21	40 ins.	125.664	1256.64	43 ins.	135.088	1452.20
⅛	116.631	1082.48	⅛	126.056	1264.50	⅛	135.481	1460.65
¼	117.024	1089.79	¼	126.449	1272.39	¼	135.874	1469.13
⅜	117.417	1097.11	⅜	126.842	1280.31	⅜	136.266	1477.63
½	117.810	1104.46	½	127.234	1288.25	½	136.659	1486.17
⅝	118.202	1111.84	⅝	127.627	1296.21	⅝	137.052	1494.72
¾	118.595	1119.24	¾	128.020	1304.20	¾	137.445	1503.30
⅞	118.988	1126.66	⅞	128.412	1312.21	⅞	137.837	1511.90
38 ins.	119.380	1134.11	41 ins.	128.805	1320.25	44 ins.	138.230	1520.53
⅛	119.773	1141.59	⅛	129.198	1328.32	⅛	138.623	1529.18
¼	120.166	1149.08	¼	129.591	1336.40	¼	139.015	1537.86
⅜	120.558	1156.61	⅜	129.983	1344.51	⅜	139.408	1546.55
½	120.951	1164.15	½	130.376	1352.65	½	139.801	1555.28
⅝	121.344	1171.73	⅝	130.769	1360.81	⅝	140.193	1564.03
¾	121.737	1179.32	¾	131.161	1369.00	¾	140.586	1572.81
⅞	122.129	1186.94	⅞	131.554	1377.21	⅞	140.979	1581.61

CIRCUMFERENCES AND AREAS OF CIRCLES.—*Continued.*

Diam.	*Circum.*	*Area.*	*Diam.*	*Circum.*	*Area.*	*Diam.*	*Circum.*	*Area.*
Ins.	Ins.	Sq. ins.	Ins.	Ins.	Sq. ins.	Ins.	Ins.	Sq. ins.
45 ins.	141.372	1590.43	48 ins.	150.796	1809.56	52 ins.	163.363	2123.72
⅛	141.764	1599.28	⅛	151.189	1818.99	¼	164.148	2144.19
¼	142.157	1608.15	¼	151.582	1828.46	½	164.934	2164.75
⅜	142.550	1617.04	⅜	151.974	1837.93	¾	165.719	2185.42
½	142.942	1625.97	½	152.367	1847.45	53 ins.	166.504	2206.18
⅝	143.335	1634.92	⅝	152.760	1856.99	¼	167.290	2227.05
¾	143.728	1643.89	¾	153.153	1866.55	½	168.075	2248.01
⅞	144.120	1652.88	⅞	153.545	1876.13	¾	168.861	2269.06
46 ins.	144.513	1661.90	49 ins.	153.938	1885.74	54 ins.	169.646	2290.22
⅛	144.906	1670.95	⅛	154.331	1895.37	¼	170.431	2311.48
¼	145.299	1680.01	¼	154.723	1905.03	½	171.217	2332.83
⅜	145.691	1689.10	⅜	155.116	1914.70	¾	172.002	2354.28
½	146.084	1698.23	½	155.509	1924.42	55 ins.	172.788	2375.83
⅝	146.477	1707.37	⅝	155.901	1934.15	¼	173.573	2397.48
¾	146.869	1716.54	¾	156.294	1943.91	½	174.358	2419.22
⅞	147.262	1725.73	⅞	156.687	1953.69	¾	175.144	2441.07
47 ins.	147.655	1734.94	50 ins.	157.080	1963.50	56 ins.	175.929	2463.01
⅛	148.047	1744.18	¼	157.865	1983.18	¼	176.715	2485.05
¼	148.440	1753.45	½	158.650	2002.96	½	177.500	2507.19
⅜	148.833	1762.73	¾	159.436	2022.84	¾	178.285	2529.42
½	149.226	1772.05	51 ins.	160.221	2042.82	57 ins.	179.071	2551.76
⅝	149.618	1781.39	¼	161.007	2062.90	¼	179.856	2574.19
¾	150.011	1790.76	½	161.792	2083.07	½	180.642	2596.72
⅞	150.404	1800.14	¾	162.577	2103.35	¾	181.427	2619.35

CIRCUMFERENCES AND AREAS OF CIRCLES.—*Continued.*

Diam.	*Circum.*	*Area.*	*Diam.*	*Circum.*	*Area.*	*Diam.*	*Circum.*	*Area.*
Ins.	Ins.	Sq. ins.	Ins.	Ins.	Sq. ins.	Ins.	Ins.	Sq. Ins.
58 ins.	182.212	2642.08	64 ins.	201.062	3216.99	70 ins.	219.912	3848.46
¼	182.998	2664.91	¼	201.847	3242.17	¼	220.697	3875.99
½	183.783	2687.83	½	202.683	3267.46	½	221.482	3903.63
¾	184.569	2710.85	¾	203.418	3292.83	¾	222.268	3931.36
59 ins.	185.354	2733.97	65 ins.	204.204	3318.31	71 ins.	223.053	3959.20
¼	186.139	2757.19	¼	204.989	3343.88	¼	223.839	3987.13
½	186.925	2780.51	½	205.774	3369.56	½	224.624	4015.16
¾	187.710	2803.92	¾	206.560	3395.33	¾	225.409	4043.28
60 ins.	188.496	2827.44	66 ins.	207.345	3421.20	72 ins.	226.195	4071.51
¼	189.281	2851.05	¼	208.131	3447.16	¼	226.980	4099.83
½	190.066	2874.76	½	208.916	3473.23	½	227.766	4128.25
¾	190.852	2898.56	¾	209.701	3499.39	¾	228.551	4156.77
61 ins.	191.637	2922.47	67 ins.	210.487	3525.66	73 ins.	229.336	4185.39
¼	192.423	2946.47	¼	211.272	3552.01	¼	230.122	4214.11
½	193.208	2970.57	½	212.058	3578.47	½	230.907	4242.92
¾	193.993	2994.77	¾	212.843	3605.03	¾	231.693	4271.83
62 ins.	194.779	3019.07	68 ins.	213.628	3631.68	74 ins.	232.478	4300.85
¼	195.564	3043.47	¼	214.414	3658.44	¼	233.263	4329.95
½	196.350	3067.96	½	215.199	3685.29	½	234.049	4359.16
¾	197.135	3092.56	¾	215.985	3712 24	¾	234.834	4388.47
63 ins.	197.920	3117.25	69 ins.	216.770	3739.28	75 ins.	235.620	4417.87
¼	198.706	3142.04	¼	217.555	3766.43	¼	236.405	4447.37
½	199.491	3166.92	½	218.341	3793.67	½	237.190	4476.97
¾	200.277	3191.91	¾	219.126	3821.02	¾	237.976	4506.67

CIRCUMFERENCES AND AREAS OF CIRCLES.—*Continued.*

Diam.	*Circum.*	*Area.*	*Diam.*	*Circum.*	*Area.*	*Diam.*	*Circum.*	*Area.*
Ins.	Ins.	Sq. ins.	Ins.	Ins.	Sq. ins.	Ins.	Ins.	Sq. ins.
76 ins.	238.761	4536.37	84 ins.	263.894	5541.78	96	301.594	7238.25
¼	239.547	4566.36	½	265.465	5607.95	97	304.735	7389.83
½	240.332	4596.35	85 ins.	267.036	5674.51	98	307.877	7542.98
¾	241.117	4626.44	½	268.606	5741.47	99	311.018	7784.10
77 ins.	241.903	4656.63	86 ins.	270.177	5808.81	100	314.159	7854.00
¼	242.688	4686.92	½	271.748	5876.55	101	317.301	8011.86
½	243.474	4717.30	87 ins.	273.319	5944.66	102	320.442	8171.30
¾	244.259	4747.79	½	274.890	6013.21	103	323.584	8332.31
78 ins.	245.044	4778.37	88 ins.	276.460	6082.13	104	326.725	8494.88
¼	245.830	4809.05	½	278.031	6151.44	105	329.867	8659.03
½	246.615	4839.83	89 ins.	279.602	6221.15	106	333.009	8824.75
¾	247.401	4870.70	½	281.173	6291.25	107	336.150	8992.04
79 ins.	248.186	4901.68	90 ins.	282.744	6361.74	108	339.292	9160.90
¼	248.971	4932.75	½	284.314	6432.62	109	342.433	9331.34
½	249.757	4963.92	91 ins.	285.885	6503.89	110	345.575	9503.34
¾	250.542	4995.19	½	287.456	6573.56			
80 ins.	251.328	5026.56	92 ins.	289.027	6647.62			
½	252.898	5089.58	½	290.598	6720.07			
81 ins.	254.469	5153.00	93 ins.	292.168	6792.92			
½	256.040	5216.82	½	293.739	6866.16			
82 ins.	257.611	5281.02	94 ins.	295.310	6939.79			
½	259.182	5345.62	½	296.881	7013.81			
83 ins.	260.752	5410.62	95 ins.	298.452	7088.23			
½	262.323	5476.00	½	300.022	7163.04			

PROPERTIES OF SATURATED STEAM.

Total pressure per square inch measured from a vacuum.	*Pressure above the atmosphere.*	*Sensible temperature in Fahrenheit degrees.*	*Total heat in degrees from zero of Fahrenheit.*	*Weight of 1 cubic foot of steam.*	*Relative volume of the steam compared with the water from which it was raised.*
Lbs.	Lbs.	Degrees.	Degrees.	Lbs.	
1	....	102.1	1144.5	.0030	20582
2	....	126.3	1151.7	.0058	10721
3	....	141.6	1156.6	.0085	7322
4	....	153.1	1160.1	.0112	5583
5	....	162.3	1162.9	.0138	4527
6	....	170.2	1165.3	.0163	3813
7	....	176.9	1167.3	.0189	3298
8	....	182.9	1169.2	.0214	2909
9	....	188.3	1170.8	.0239	2604
10	...	193.3	1172.3	.0264	2358
11	....	197.8	1173.7	.0289	2157
12	....	202.0	1175.0	.0314	1986
13	....	205.9	1176.2	.0338	1842
14	....	209.6	1177.3	.0362	1720
14.7	...	212.0	1178.1	.0380	1642
15	.3	213.1	1178.4	.0387	1610
16	1.3	216.3	1179.4	.0411	1515
17	2.3	219.6	1180.3	.0435	1431
18	3.3	222.4	1181.2	.0459	1357
19	4.3	225.3	1182.1	.0483	1290
20	5.3	228.0	1182.9	.0507	1229
21	6.3	230.6	1183.7	.0531	1174
22	7.3	233.1	1184.5	.0555	1123
23	8.3	235.5	1185.2	.0580	1075
24	9.3	237.8	1185.9	.0601	1036

PROPERTIES OF SATURATED STEAM.—*Continued.*

Total pressure per square inch measured from a vacuum.	*Pressure above the atmosphere.*	*Sensible temperature in Fahrenheit degrees.*	*Total heat in degrees from zero of Fahrenheit.*	*Weight of 1 cubic foot of steam.*	*Relative volume of the steam compared with the water from which it was raised.*
Lbs.	Lbs.	Degrees.	Degrees.	Lbs.	
25	10.3	240.1	1186.6	.0625	996
26	11.3	242.3	1187.3	.0650	958
27	12.3	244.4	1187.8	.0673	926
28	13.3	246.4	1188.4	.0696	895
29	14.3	248.4	1189.1	.0719	866
30	15.3	250.4	1189.8	.0743	838
31	16.3	252.2	1190.4	.0766	813
32	17.3	254.1	1190.9	.0789	789
33	18.3	255.9	1191.5	.0812	767
34	19.3	257.6	1192.0	.0835	746
35	20.3	259.3	1192.5	.0858	726
36	21.3	260.9	1193.0	.0881	707
37	22.3	262.6	1193.5	.0905	688
38	23.3	264.2	1194.0	.0929	671
39	24.3	265.8	1194.5	.0952	655
40	25.3	267.3	1194.9	.0974	640
41	26.3	268.7	1195.4	.0996	625
42	27.3	270.2	1195.8	.1020	611
43	28.3	271.6	1196.2	.1042	598
44	29.3	273.0	1196.6	.1065	585
45	30.3	274.4	1197.1	.1089	572
46	31.3	275.8	1197.5	.1111	561
47	32.3	277.1	1197.9	.1133	550
48	33.3	278.4	1198.3	.1156	539
49	34.3	279.7	1198.7	.1179	529

PROPERTIES OF SATURATED STEAM.—*Continued.*

Total pressure per square inch measured from a vacuum.	*Pressure above the atmosphere.*	*Sensible temperature in Fahrenheit degrees.*	*Total heat in degrees from zero of Fahrenheit.*	*Weight of 1 cubic foot of steam.*	*Relative volume of the steam compared with the water from which it was raised.*
Lbs.	Lbs.	Degrees.	Degrees.	Lbs.	
50	35.3	281.0	1199.1	.1202	518
51	36.3	282.3	1199.5	.1224	509
52	37.3	283.5	1199.9	.1246	500
53	38.3	284.7	1200.3	.1269	491
54	39.3	285.9	1200.6	.1291	482
55	40.3	287.1	1201.0	.1314	474
56	41.3	288.2	1201.3	.1336	466
57	42.3	289.3	1201.7	.1364	458
58	43.3	290.4	1202.0	.1380	451
59	44.3	291.6	1202.4	.1403	444
60	45.3	292.7	1202.7	.1425	437
61	46.3	293.8	1203.1	.1447	430
62	47.3	294.8	1203.4	.1469	424
63	48.3	295.9	1203.7	.1493	417
64	49.3	296.9	1204.0	.1516	411
65	50.3	298.0	1204.3	.1538	405
66	51.3	299.0	1204.6	.1560	399
67	52.3	300.0	1204.9	.1583	393
68	53.3	300.9	1205.2	.1605	388
69	54.3	301.9	1205.5	.1627	383
70	55.3	302.9	1205.8	.1648	378
71	56.3	303.9	1206.1	.1670	373
72	57.3	304.8	1206.3	.1692	368
73	58.3	305.7	1206.6	.1714	363
74	59.3	306.6	1206.9	.1736	359

PROPERTIES OF SATURATED STEAM.—*Continued.*

Total pressure per square inch measured from a vacuum.	*Pressure above the atmosphere.*	*Sensible temperature in Fahrenheit degrees.*	*Total heat in degrees from zero of Fahrenheit.*	*Weight of 1 cubic foot of steam.*	*Relative volume of the steam compared with the water from which it was raised.*
Lbs.	Lbs.	Degrees.	Degrees.	Lbs.	
75	60.3	307.5	1207.2	.1759	353
76	61.3	308.4	1207.4	.1782	349
77	62.3	309.3	1207.7	.1804	345
78	63.3	310.2	1208.0	.1826	341
79	64.3	311.1	1208.3	.1848	337
80	65.3	312.0	1208.5	.1869	333
81	66.3	312.8	1208.8	.1891	329
82	67.3	313.6	1209.1	.1913	325
83	68.3	314.5	1209.4	.1935	321
84	69.3	315.3	1209.6	.1957	318
85	70.3	316.2	1209.9	.1980	314
86	71.3	317.8	1210.1	.2002	311
87	72.3	318.6	1210.4	.2024	308
88	73.3	319.4	1210.6	.2044	305
89	74.3	320.2	1210.9	.2067	301
90	75.3	321.0	1211.1	.2089	298
91	76.3	321.7	1211.3	.2111	295
92	77.3	322.5	1211.5	.2133	292
93	78.3	323.3	1211.8	.2155	289
94	79.3	324.1	1212.0	.2176	286
95	80.3	324.8	1212.3	.2198	283
96	81.3	325.6	1212.5	.2219	281
97	82.3	326.3	1212.8	.2241	278
98	83.3	327.1	1213.0	.2263	275
99	84.3	327.9	1213.2	.2285	272

PROPERTIES OF SATURATED STEAM.—*Continued.*

Total pressure per square inch measured from a vacuum.	*Pressure above the atmosphere.*	*Sensible temperature in Fahrenheit degrees.*	*Total heat in degrees from zero of Fahrenheit.*	*Weight of 1 cubic foot of steam.*	*Relative volume of the steam compared with the water from which it was raised.*
Lbs.	Lbs.	Degrees.	Degrees.	Lbs.	
100	85.3	327.9	1213.4	.2307	270
101	86.3	328.5	1213.6	.2329	267
102	87.3	329.1	1213.8	.2351	265
103	88.3	329.9	1214.0	.2373	262
104	89.3	330.6	1214.2	.2393	260
105	90.3	331.3	1214.4	.2414	257
106	91.3	331.9	1214.6	.2435	255
107	92.3	332.6	1214.8	.2456	253
108	93.3	333.3	1215.0	.2477	251
109	94.3	334.0	1215.3	.2499	249
110	95.3	334.6	1215.5	.2521	247
111	96.3	335.3	1215.7	.2543	245
112	97.3	336.0	1215.9	.2564	243
113	98.3	336.7	1216.1	.2586	241
114	99.3	337.4	1216.3	.2607	239
115	100.3	338.0	1216.5	.2628	237
116	101.3	338.6	1216.7	.2649	235
117	102.3	339.3	1216.9	.2674	233
118	103.3	339.9	1217.1	.2696	231
119	104.3	340.5	1217.3	.2738	229
120	105.3	341.1	1217.4	.2759	227
121	106.3	341.8	1217.6	.2780	225
122	107.3	342.4	1217.8	.2801	224
123	108.3	343.0	1218.0	.2822	222
124	109.3	343.6	1218.2	.2845	221

PROPERTIES OF SATURATED STEAM.—*Continued.*

Total pressure per square inch measured from a vacuum.	*Pressure above the atmosphere.*	*Sensible temperature in Fahrenheit degrees.*	*Total heat in degrees from zero of Fahrenheit.*	*Weight of 1 cubic foot of steam.*	*Relative volume of the steam compared with the water from which it was raised.*
Lbs.	Lbs.	Degrees.	Degrees.	Lbs.	
125	110.3	344.2	1218.4	.2867	219
126	111.3	344.8	1218.6	.2889	217
127	112.3	345.4	1218.8	.2911	215
128	113.3	346.0	1218.9	.2933	214
129	114.3	346.6	1219.1	.2955	212
130	115.3	347.2	1219.3	.2977	211
131	116.3	347.8	1219.5	.2999	209
132	117.3	348.3	1219.6	.3020	208
133	118.3	348.9	1219.8	.3040	206
134	119.3	349.5	1220.0	.3060	205
135	120.3	350.1	1220.2	.3080	203
136	121.3	350.6	1220.3	.3101	202
137	122.3	351.2	1220.5	.3121	200
138	123.3	351.8	1220.7	.3142	199
139	124.3	352.4	1220.9	.3162	198
140	125.3	352.9	1221.0	.3184	197
141	126.3	353.5	1221.2	.3206	195
142	127.3	354.0	1221.4	.3228	194
143	128.3	354.5	1221.6	.3250	193
144	129.3	355.0	1221.7	.3273	192
145	130.3	355.6	1221.9	.3294	190
146	131.3	356.1	1222.0	.3315	189
147	132.3	356.7	1222.2	.3336	188
148	133.3	357.2	1222.3	.3357	187
149	134.3	357.8	1222.5	.3377	186

PROPERTIES OF SATURATED STEAM.—*Continued.*

Total pressure per square inch measured from a vacuum.	*Pressure above the atmosphere.*	*Sensible temperature in Fahrenheit degrees.*	*Total heat in degrees from zero of Fahrenheit.*	*Weight of 1 cubic foot of steam.*	*Relative volume of the steam compared with the water from which it is raised.*
Lbs.	Lbs.	Degrees.	Degrees.	Lbs.	
150	135.3	358.3	1222.7	.3397	184
155	140.3	361.0	1223.5	.3500	179
160	145.3	363.4	1224.2	.3607	174
165	150.3	366.0	1224.9	.3714	169
170	155.3	368.2	1225.7	.3821	164
175	160.3	370.8	1226.4	.3928	159
180	165.3	372.9	1227.1	.4035	155
185	170.3	375.3	1227.8	.4142	151
190	175.3	377.5	1228.5	.4250	148
195	180.3	379.7	1229.2	.4357	144
200	185.3	381.7	1229.8	.4464	141
210	195.3	386.0	1231.1	.4668	135
220	205.3	389.9	1232.3	.4872	129
230	215.3	393.8	1233.5	.5072	123
240	225.3	397.5	1234.6	.5270	119
250	235.3	401.1	1235.7	.5471	114
260	245.3	404.5	1236.8	.5670	110
270	255.3	407.9	1237.8	.5871	106
280	265.3	411.2	1238.8	.6070	102
290	275.3	414.4	1239.8	.6268	99
300	285.3	417.5	1240.7	.6469	96

HYPERBOLIC LOGARITHMS.

N.	*Log.*	*N.*	*Log.*	*N.*	*Log.*
1.01	0.00995	1.31	0.27003	1.61	0.47623
1.02	0.01980	1.32	0.27763	1.62	0.48243
1.03	0.02156	1.33	0.28518	1.63	0.48858
1.04	0.03922	1.34	0.29267	1.64	0.49470
1.05	0.04879	1.35	0.30010	1.65	0.50077
1.06	0.05827	1.36	0.30748	1.66	0.50682
1.07	0.06766	1.37	0.31481	1.67	0.51282
1.08	0.07696	1.38	0.32208	1.68	0.51879
1.09	0.08718	1.39	0.32930	1.69	0.52473
1.10	0.09531	1.40	0.33647	1.70	0.53063
1.11	0.10436	1.41	0.34359	1.71	0.53649
1.12	0.11333	1.42	0.35066	1.72	0.54232
1.13	0.12222	1.43	0.35767	1.73	0.54812
1.14	0.13103	1.44	0.36464	1.74	0.55389
1.15	0.13976	1.45	0.37156	1.75	0.55962
1.16	0.14842	1.46	0.37844	1.76	0.56531
1.17	0.15700	1.47	0.38526	1.77	0.57098
1.18	0.16551	1.48	0.39204	1.78	0.57661
1.19	0.17395	1.49	0.39878	1.79	0.58222
1.20	0.18232	1.50	0.40547	1.80	0.58779
1.21	0.19062	1.51	0.41211	1.81	0.59333
1.22	0.19885	1.52	0.41871	1.82	0.59884
1.23	0.20701	1.53	0.42527	1.83	0.60432
1.24	0.21511	1.54	0.43178	1.84	0.60977
1.25	0.22314	1.55	0.43825	1.85	0.61519
1.26	0.23111	1.56	0.44469	1.86	0.62058
1.27	0.23902	1.57	0.45108	1.87	0.62584
1.28	0.24686	1.58	0.45742	1.88	0.63127
1.29	0.25464	1.59	0.46373	1.89	0.63658
1.30	0.26236	1.60	0.47000	1.90	0.64185

HYPERBOLIC LOGARITHMS.—*Continued.*

N.	Log.	N.	Log.	N.	Log.
1.91	0.64710	2.21	0.79299	2.51	0.92028
1.92	0.65233	2.22	0.79751	2.52	0.92426
1.93	0.65752	2.23	0.80200	2.53	0.92822
1.94	0.66269	2.24	0.80648	2.54	0.93216
1.95	0.66783	2.25	0.81093	2.55	0.93609
1.96	0.67294	2.26	0.81536	2.56	0.94001
1.97	0.67803	2.27	0.81978	2.57	0.94301
1.98	0.68310	2.28	0.82418	2.58	0.94779
1.99	0.68813	2.29	0.82855	2.59	0.95166
2.00	0.69315	2.30	0.83291	2.60	0.95551
2.01	0.69813	2.31	0.83725	2.61	0.95935
2.02	0.70310	2.32	0.84157	2.62	0.96317
2.03	0.70804	2.33	0.84587	2.63	0.96698
2.04	0.71295	2.34	0.85015	2.64	0.97078
2.05	0.71784	2.35	0.85442	2.65	0.97456
2.06	0.72271	2.36	0.85866	2.66	0.97833
2.07	0.72755	2.37	0.86289	2.67	0.98208
2.08	0.73237	2.38	0.86710	2.68	0.98582
2.09	0.73716	2.39	0.87129	2.69	0.98954
2.10	0.74194	2.40	0.87547	2.70	0.99325
2.11	0.74669	2.41	0.87963	2.71	0.99695
2.12	0.75142	2.42	0.88377	2.72	1.00063
2.13	0.75612	2.43	0.88789	2.73	1.00430
2.14	0.76081	2.44	0.89200	2.74	1.00796
2.15	0.76547	2.45	0.89609	2.75	1.01160
2.16	0.77011	2.46	0.90010	2.76	1.01523
2.17	0.77471	2.47	0.90422	2.77	1.01885
2.18	0.77932	2.48	0.90826	2.78	1.02245
2.19	0.78391	2.49	0.91228	2.79	1.02604
2.20	0.78846	2.50	0.91629	2.80	1.02962

HYPERBOLIC LOGARITHMS.—*Continued.*

N.	Log.	N.	Log.	N.	Log.
2.81	1.03318	3.11	1.13462	3.41	1.22671
2.82	1.03674	3.12	1.13783	3.42	1.22964
2.83	1.04028	3.13	1.14103	3.43	1.23256
2.84	1.04380	3.14	1.14422	3.44	1.23547
2.85	1.04732	3.15	1.14740	3.45	1.23837
2.86	1.05082	3.16	1.15057	3.46	1.24187
2.87	1.05431	3.17	1.15373	3.47	1.24415
2.88	1.05779	3.18	1.15688	3.48	1.24703
2.89	1.06126	3.19	1.16002	3.49	1.24990
2.90	1.06471	3.20	1.16315	3.50	1.25276
2.91	1.06815	3.21	1.16627	3.51	1.25562
2.92	1.07158	3.22	1.16938	3.52	1.25846
2.93	1.07500	3.23	1.17248	3.53	1.26130
2.94	1.07841	3.24	1.17557	3.54	1.26413
2.95	1.08181	3.25	1.17865	3.55	1.26695
2.96	1.08519	3.26	1.18173	3.56	1.26976
2.97	1.08856	3.27	1.18479	3.57	1.27257
2.98	1.09192	3.28	1.18784	3.58	1.27536
2.99	1.09527	3.29	1.19089	3.59	1.27815
3.00	1.09861	3.30	1.19392	3.60	1.28093
3.01	1.10194	3.31	1.19695	3.61	1.28371
3.02	1.10526	3.32	1.19996	3.62	1.28647
3.03	1.10856	3.33	1.20297	3.63	1.28923
3.04	1.11186	3.34	1.20597	3.64	1.29198
3.05	1.11514	3.35	1.20896	3.65	1.29473
3.06	1.11841	3.36	1.21194	3.66	1.29746
3.07	1.12168	3.37	1.21491	3.67	1.30019
3.08	1.12493	3.38	1.21788	3.68	1.30291
3.09	1.12817	3.39	1.22083	3.69	1.30563
3.10	1.13410	3.40	1.22378	3.70	1.30833

HYPERBOLIC LOGARITHMS.—*Continued.*

N.	*Log.*	*N.*	*Log.*	*N.*	*Log.*
3.71	1.31103	4.01	1.38879	4.31	1.46094
3.72	1.31372	4.02	1.39128	4.32	1.46326
3.73	1.31641	4.03	1.39377	4.33	1.46557
3.74	1.31909	4.04	1.39624	4.34	1.46787
3.75	1.32176	4.05	1.39872	4.35	1.47018
3.76	1.32442	4.06	1.40118	4.36	1.47247
3.77	1.32707	4.07	1.40364	4.37	1.47476
3.78	1.32972	4.08	1.40610	4.38	1.47705
3.79	1.33237	4.09	1.40854	4.39	1.47933
3.80	1.33500	4.10	1.40099	4.40	1.48160
3.81	1.33763	4.11	1.41342	4.41	1.48387
3.82	1.34025	4.12	1.41585	4.42	1.48614
3.83	1.34286	4.13	1.41828	4.43	1.48840
3.84	1.34547	4.14	1.42070	4 44	1.49065
3.85	1.34807	4.15	1.42311	4.45	1.49290
3.86	1.35067	4.16	1.42552	4.46	1.49535
3.87	1.35325	4.17	1.42792	4.47	1.49739
3.88	1.35584	4.18	1.43031	4.48	1.49962
3.89	1.35841	4.19	1.43270	4.49	1.50185
3.90	1.36098	4.20	1.43508	4.50	1.50408
3.91	1.36354	4.21	1.43746	4.51	1.50630
3.92	1.36609	4.22	1.43984	4.52.	1.50851
3.93	1.36864	4.23	1.44220	4.53	1.51072
3.94	1.37118	4.24	1.44456	4.54	1.51293
3.95	1.37372	4.25	1.44692	4.55	1.51513
3.96	1.37624	4.26	1.44927	4.56	1.51732
3.97	1.37877	4.27	1.45161	4.57	1.51951
3.98	1.38128	4.28	1.45395	4.58	1.52170
3.99	1.38379	4.29	1.45629	4.59	1.52388
4.00	1.38629	4.30	1.45862	4.60	1.52606

HYPERBOLIC LOGARITHMS.—*Continued.*

N.	Log.	N.	Log.	N.	Log.
4.61	1.52823	4.91	1.59127	5.21	1.65058
4.62	1.53039	4.92	1.59331	5.22	1.65250
4.63	1.53256	4.93	1.59534	5.23	1.65451
4.64	1.53471	4.94	1.59737	5.24	1.65632
4.65	1.53687	4.95	1.59939	5.25	1.65822
4.66	1.53902	4.96	1.60141	5.26	1.66013
4.67	1.54116	4.97	1.60342	5.27	1.66203
4.68	1.54330	4.98	1.60543	5.28	1.66393
4.69	1.54543	4.99	1.60744	5.29	1.66582
4.70	1.54756	5.00	1.60944	5.30	1.66771
4.71	1.54969	5.01	1.61144	5.31	1.66959
4.72	1.55181	5.02	1.61343	5.32	1.67147
4.73	1.55393	5.03	1.61542	5.33	1.67335
4.74	1.55604	5.04	1.61741	5.34	1.67523
4.75	1.55814	5.05	1.61939	5.35	1.67710
4.76	1.56025	5.06	1.62137	5.36	1.67896
4.77	1.56235	5.07	1.62334	5.37	1.68083
4.78	1.56444	5.08	1.62531	5.38	1.68269
4.79	1.56653	5.09	1.62728	5.39	1.68455
4.80	1.56862	5.10	1.62924	5.40	1.68640
4.81	1.57070	5.11	1.63120	5.41	1.68825
4.82	1.57277	5.12	1.63315	5.42	1.69010
4.83	1.57485	5.13	1.63511	5.43	1.69194
4.84	1.57691	5.14	1.63705	5.44	1.69378
4.85	1.57898	5.15	1.63900	5.45	1.69562
4.86	1.58104	5.16	1.64094	5.46	1.69745
4.87	1.58309	5.17	1.64287	5.47	1.69928
4.88	1.58515	5.18	1.64481	5.48	1.70111
4.89	1.58719	5.19	1.64673	5.49	1.70293
4.90	1.58924	5.20	1.64866	5.50	1.70475

HYPERBOLIC LOGARITHMS.

N.	Log.	N.	Log.	N.	Log.
5.51	1.70656	5.81	1.75958	6.11	1.80993
5.52	1.70838	5.82	1.76130	6.12	1.81156
5.53	1.71019	5.83	1.76302	6.13	1.81319
5.54	1.71199	5.84	1.76473	6.14	1.81482
5.55	1.71380	5.85	1.76644	6.15	1.81645
5.56	1.71560	5.86	1.76815	6.16	1.81808
5.57	1.71740	5.87	1.76985	6.17	1.81970
5.58	1.71919	5.88	1.77156	6.18	1.82132
5.59	1.72098	5.89	1.77326	6.19	1.82294
5.60	1.72277	5.90	1.77495	6.20	1.82455
5.61	1.72455	5.91	1.77665	6.21	1.82616
5.62	1.72633	5.92	1.77834	6.22	1.82777
5.63	1.72811	5.93	1.78002	6.23	1.82938
5.64	1.72988	5.94	1.78171	6.24	1.83098
5.65	1.73166	5.95	1.78339	6.25	1.83258
5.66	1.73342	5.96	1.78507	6.26	1.83418
5.67	1.73519	5.97	1.78675	6.27	1.83578
5.68	1.73695	5.98	1.78842	6.28	1.83737
5.69	1.73871	5.99	1.79009	6.29	1.83896
5.70	1.74047	6.00	1.79176	6.30	1.84055
5.71	1.74222	6.01	1.79342	6.31	1.84214
5.72	1.74397	6.02	1.79509	6.32	1.84372
5.73	1.74572	6.03	1.79675	6.33	1.84530
5.74	1.74746	6.04	1.79840	6.34	1.84688
5.75	1.74912	6.05	1.80006	6.35	1.84845
5.76	1.75094	6.06	1.80171	6.36	1.85003
5.77	1.75267	6.07	1.80336	6.37	1.85160
5.78	1.75440	6.08	1.80500	6.38	1.85317
5.79	1.75613	6.09	1.80665	6.39	1.85473
5.80	1.75786	6.10	1.80829	6.40	1.85630

HYPERBOLIC LOGARITHMS.—*Continued.*

N.	Log.	N.	Log.	N.	Log.
6.41	1.85786	6.71	1.90360	7.01	1.94734
6.42	1.85942	6.72	1 90509	7.02	1.94876
6.43	1.86097	6.73	1.90658	7.03	1.95019
6.44	1.86253	6.74	1.90806	7.04	1.95161
6.45	1.86408	6.75	1.90954	7.05	1.95303
6.46	1.86563	6.76	1.91102	7.06	1.95445
6.47	1.86718	6.77	1.91250	7.07	1.95586
6.48	1.86872	6.78	1.91398	7.08	1.95727
6.49	1.87026	6.79	1.91545	7.09	1.95869
6.50	1.87180	6.80	1.91692	7.10	1.96009
6.51	1.87334	6.81	1.91839	7.11	1.96150
6.52	1.87487	6.82	1.91986	7.12	1.96291
6.53	1.87641	6.83	1.92132	7.13	1.96431
6.54	1.87794	6.84	1.92279	7.14	1.96571
6.55	1.87947	6.85	1.92425	7.15	1.96711
6.56	1.88099	6.86	1.92571	7.16	1.96851
6.57	1.88251	6.87	1.92716	7.17	1.96991
6.58	1.88403	6.88	1.92862	7.18	1.97130
6.59	1.88555	6.89	1.93007	7.19	1.97269
6.60	1.88707	6.90	1.93152	7.20	1.97408
6.61	1.88858	6.91	1.93297	7.21	1.97547
6.62	1.89010	6.92	1.93442	7.22	1.97685
6.63	1.89160	6.93	1.93586	7.23	1.97824
6.64	1.89311	6.94	1.93730	7.24	1.97962
6.65	1.89462	6.95	1.93874	7.25	1.98100
6.66	1.89612	6.96	1.94018	7.26	1.98238
6.67	1.89762	6.97	1.94162	7.27	1.98376
6.68	1.89912	6.98	1.94305	7 28	1.98513
6.69	1.90061	6.99	1.94448	7.29	1.98650
6.70	1.90210	7.00	1.94591	7.30	1.98787

HYPERBOLIC LOGARITHMS.—*Continued.*

N.	Log.	N.	Log.	N.	Log.
7.31	1.98924	7.61	2.02946	7.91	2.06813
7.32	1.99061	7.62	2.03078	7.92	2.06939
7.33	1.99198	7.63	2.03209	7.93	2.07065
7.34	1.99334	7.64	2.03340	7.94	2.07191
7.35	1.99470	7.65	2.03471	7.95	2.07317
7.36	1.99606	7.66	2.03601	7.96	2.07443
7.37	1.99742	7.67	2.03732	7.97	2.07568
7.38	1.99878	7.68	2.03862	7.98	2.07694
7.39	2.00013	7.69	2.03993	7.99	2.07819
7.40	2.00148	7.70	2.04122	8.00	2.07944
7.41	2.00283	7.71	2.04252	8.01	2.08069
7.42	2.00418	7.72	2.04381	8.02	2.08194
7.43	2.00553	7.73	2.04511	8.03	2.08318
7.44	2.00687	7.74	2.04640	8.04	2.08443
7.45	2.00821	7.75	2.04769	8.05	2.08567
7.46	2.00956	7.76	2.04898	8.06	2.08691
7.47	2.01089	7.77	2.05027	8.07	2.08815
7.48	2.01223	7.78	2.05156	8.08	2.08939
7.49	2.01357	7.79	2.05284	8.09	2.09063
7.50	2.01490	7.80	2.05412	8.10	2.09186
7.51	2.01624	7.81	2.05540	8.11	2.09310
7.52	2.01757	7.82	2.05668	8.12	2.09433
7.53	2.01890	7.83	2.05796	8.13	2.09556
7.54	2.02022	7.84	2.05924	8.14	2.09679
7.55	2.02155	7.85	2.06051	8.15	2.09882
7.56	2.02287	7.86	2.06179	8.16	2.09924
7.57	2.02419	7.87	2.06306	8.17	2.10047
7.58	2.02551	7.88	2.06433	8.18	2.10169
7.59	2.02683	7.89	2.06560	8.19	2.10291
7.60	2.02815	7.90	2.06686	8.20	2.10413

HYPERBOLIC LOGARITHMS.—*Continued.*

N.	*Log.*	*N.*	*Log.*	*N.*	*Log.*
8.21	2.10535	8.51	2.14124	8.81	2.17589
8.22	2.10657	8.52	2.14242	8.82	2.17702
8.23	2.10779	8.53	2.14359	8.83	2.17815
8.24	2.10900	8.54	2.14476	8.84	2.17929
8.25	2.11021	8.55	2.14593	8.85	2.18042
8.26	2.11142	8.56	2.14710	8.86	2.18155
8.27	2.11263	8.57	2.14827	8.87	2.18267
8.28	2.11384	8.58	2.14943	8.88	2.18380
8.29	2.11505	8.59	2.15060	8.89	2.18492
8.30	2.11626	8.60	2.15176	8.90	2.18605
8.31	2.11750	8.61	2.15292	8.91	2.18717
8.32	2.11866	8.62	2.15409	8.92	2.18830
8.33	2.11986	8.63	2.15524	8.93	2.18942
8.34	2.12006	8.64	2.15641	8.94	2.19054
8.35	2.12226	8.65	2.15756	8.95	2.19165
8.36	2.12346	8.66	2.15871	8.96	2.19277
8.37	2.12465	8.67	2.15987	8.97	2.19389
8.38	2.12585	8.68	2.16102	8.98	2.19500
8.39	2.12704	8.69	2.16217	8.99	2.19611
8.40	2.12823	8.70	2.16332	9.00	2.19722
8.41	2.12942	8.71	2.16447	9.01	2.19834
8.42	2.13061	8.72	2.16562	9.02	2.19944
8.43	2.13180	8.73	2.16677	9.03	2.20055
8.44	2.13298	8.74	2.16791	9.04	2.20166
8.45	2.13417	8.75	2.16905	9.05	2.20277
8.46	2.13535	8.76	2.17020	9.06	2.20387
8.47	2.13653	8.77	2.17134	9.07	2.20497
8.48	2.13771	8.78	2.17248	9.08	2.20607
8.49	2.13889	8.79	2.17361	9.09	2.20717
8.50	2.14007	8.80	2.17475	9.10	2.20827

HYPERBOLIC LOGARITHMS.—*Continued.*

N.	*Log.*	*N.*	*Log.*	*N.*	*Log.*
9.11	2.20937	9.41	2.24177	9.71	2.27316
9.12	2.21047	9.42	2.24284	9.72	2.27419
9.13	2.21157	9.43	2.24390	9.73	2.27521
9.14	2.21266	9.44	2.24496	9.74	2.27624
9.15	2.21375	9.45	2.24601	9.75	2.27727
9.16	2.21485	9.46	2.24707	9.76	2.27829
9.17	2.21594	9.47	2.24813	9.77	2.27932
9.18	2.21703	9.48	2.24918	9.78	2.28034
9.19	2.21812	9.49	2.25024	9.79	2.28136
9.20	2.21920	9.50	2.25129	9.80	2.28238
9.21	2.22029	9.51	2.25234	9.81	2.28340
9.22	2.22137	9.52	2.25339	9.82	2.28442
9.23	2.22246	9.53	2.25444	9.83	2.28544
9.24	2.22354	9.54	2.25549	9.84	2.28646
9.25	2.22462	9.55	2.25654	9.85	2.28747
9.26	2.22570	9.56	2.25759	9.86	2.28849
9.27	2.22786	9.57	2.25863	9.87	2.28950
9.28	2.22894	9.58	2.25968	9.88	2.29051
9.29	2.23001	9.59	2.26072	9.89	2.29152
9.30	2.23101	9.60	2.26176	9.90	2.29253
9.31	2.23109	9.61	2.26280	9.91	2.29354
9.32	2.23216	9.62	2.26384	9.92	2.29455
9.33	2.23324	9.63	2.26488	9.93	2.29556
9.34	2.23431	9.64	2.26592	9.94	2.29657
9.35	2.23538	9.65	2.26696	9.95	2.29757
9.36	2.23645	9.66	2.26799	9.96	2.29858
9.37	2.23751	9.67	2.26903	9.97	2.29958
9.38	2.23858	9.68	2.27006	9.98	2.30058
9.39	2.23965	9.69	2.27109	9.99	2.30158
9.40	2.24071	9.70	2.27213	10.00	2.30259

HYPERBOLIC LOGARITHMS.—*Continued.*

N.	*Log.*	*N.*	*Log.*	*N.*	*Log.*
10.25	2.32728	14.00	2.63906	21.00	3.04452
10.50	2.35137	14.25	2.65445	22.00	3.09104
10.75	2.37490	14.50	2.67415	23.00	3.13549
11.00	2.39789	14.75	2.69124	24.00	3.17805
11.25	2.42037	15.00	2.71035	25.00	3.21887
11.50	2.44235	15.50	2.74084	30.00	3.37817
11.75	2.46385	16.00	2.77512	40.00	3.68887
12.00	2.48491	16.50	2.80336	50.00	3.91202
12.25	2.50553	17.00	2.83321	60.00	4.09434
12.50	2.52573	17.50	2.86220	70.00	4.24849
12.75	2.54553	18.00	2.89037	80.00	4.38203
13.00	2.56264	18.50	2.91754	90.00	4.49981
13.25	2.58400	19.00	2.94444	100.00	4.60287
13.50	2.60269	19.50	2.97415	1000.0	6.90776
13.75	2.62104	20.00	2.99573	10000.	9.21034

DIMENSIONS OF SAFETY-VALVE (SPRING-LOADED) FOR BOILERS—1 SQUARE INCH OF AREA ALLOWED TO EVERY 3 SQUARE FEET OF GRATE.

Diameter.	*Area.*	*Grate Surface.*	*Horse Power.*
Inches.	Sq. Inches.	Sq. Feet.	
1	.7854	2.25	7 to 9
1¼	1.2272	3.68	10 to 12
1½	1.7671	5.30	20
2	3.1416	9.42	35
2½	4.9087	14.72	55 to 60
3	7.0686	21.20	80 to 85
3½	9.6211	28.86	115
4	12.5664	37.70	150
4½	15.9043	47.71	180 to 190
5	19.635	58.9	230 to 235

TABLE OF PRESSURES ALLOWABLE ON BOILERS.

Diameter of boiler.	Thickness of plates.	45,000 *tensile strength.* 1-6, 7,500.		50,000 *tensile strength.* 1-6, 8,333.3.		55,000 *tensile strength.* 1-6, 9,166.6.		60,000 *tensile strength.* 1-6, 10,000.		65,000 *tensile strength.* 1-6, 10,833.3.		70,000 *tensile strength.* 1-6, 11,666.6.	
		Pressure.	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*
36 inches.	.1875	78.12	93.74	86.8	104.16	95.48	114.57	104.16	124.99	112.84	135.4	121.52	145.82
	.21	87.5	105.	97.21	116.65	106.94	128.3	116.66	139.99	126.38	151.65	136.11	163 33
	.23	95.83	114.99	106.47	127.76	117.12	140.54	127.77	153.32	138.41	166.09	149 07	178.88
	.25	104.16	124.99	115.74	138.88	127.31	152.77	138.88	166.65	150.46	180.55	162.03	194.43
	.26	108.33	129.99	120.37	144.44	132.4	158.88	144.44	173.32	156.48	187.77	168.51	202.21
	.29	120.83	144.99	134.25	161.11	147.68	177.21	161.11	193.33	174.53	209.43	187.90	225.48
	.3125	130.2	156 24	144.67	173.6	159.14	190.96	173.6	208.32	188.07	225.68	202.5	243.04
	.33	137.5	165.	152.77	183.32	168.05	201.66	183.33	219.99	198.61	238.33	213.88	256.65
	.35	145.83	174.99	162.03	194.43	178.23	213.87	194.44	233.32	210.64	252.76	226.84	272.20
	.375	156.25	187.5	173.61	208.33	190.97	229.16	208.33	249.99	225.69	271.82	243.05	291.66
38 inches.	.1875	74.01	88.89	82.23	98.67	90.46	108.54	98.68	118 41	106.9	128.28	115.13	138.16
	.21	82.89	99.46	92.1	110.52	101.31	121.57	110.52	132.62	119.73	143.67	128.93	154.71
	.23	90.78	108.93	100.87	121.04	110.96	133.15	121.05	145.26	131.13	157.35	141.22	169.46
	.25	98.68	118.41	109.64	131.56	120.61	144.73	131.57	157.88	142.54	171.04	153.5	184.20
	.26	102.63	123.15	114.03	136.83	125.43	150.51	136.84	164.2	148.24	177.88	159.64	191.56
	.29	114.47	137.36	127.19	152.62	139.91	167.89	152.63	183.15	165.35	198.42	178.06	213.67
	.3125	123.35	148.02	137.	164.46	150.76	180.91	164.47	197.36	178.17	213.8	191.88	230.25
	.33	130.26	156.31	144.73	173.67	159.2	191.04	173.68	208.41	188.15	225.78	202.62	243.14
	.35	138.15	165.78	153.5	184.21	168.85	202.62	184.21	221.05	199.56	239.47	214.91	257.89
	.375	148.	177.60	164.73	197.67	180 91	217.09	197.36	236.83	213.81	256.57	230.26	276.31
40 inches.	.1875	70.31	84.37	78.12	93.74	85.93	103.11	93.75	112.5	101.56	121.87	109.37	131.24
	.21	78.75	94.50	87.49	104.98	96.24	115.48	105.	126.	113.74	136.48	122.49	146.98
	.23	86.25	103.5	95.83	114.99	105.41	126.49	115.	138.	124 58	149.49	134 16	160.99
	.25	93.75	112.5	104.16	124.99	114.58	137.49	125.	150.	135.41	162.49	145.83	174.99
	.26	97.5	117.	108.33	129.99	119.16	142.99	130	156.	140.83	168.99	151.66	181.99
	.29	108.75	130.5	120.83	144.99	132.91	159.49	145.	174.	157.08	188.49	169.16	202.99
	.3125	117.18	140.61	130.2	156.24	143.22	171.86	156.25	187.45	169.27	203.12	182.29	218.74
	.33	123.75	148.5	137.49	164.98	151.24	181.48	165.	198.	178.74	214.48	192.49	230.98
	.35	131.25	157.5	145.83	174.99	160.41	192.49	175.	210.	189.58	227.49	204.16	244.99
	.375	140.62	168.74	156.24	187.48	171.87	206.24	187.5	225	203.12	243.74	218 74	262.48

TABLE OF PRESSURES ALLOWABLE ON BOILERS.— *Continued.*

Diameter of boiler.	Thickness of plates.	45,000 *tensile strength.* 1-6, 7,500.		50,000 *tensile strength.* 1-6, 8,333.3.		55,000 *tensile strength.* 1-6, 9,166.6.		60,000 *tensile strength.* 1-6, 10,000.		65,000 *tensile strength.* 1-6, 10,833.3.		70,000 *tensile strength.* 1-6, 11,666.6.	
		Pressure.	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*
42 inches.	.1875	66.96	80.35	74.40	89.28	81.84	98.20	89.28	107.13	96.72	116.06	104.16	124.99
	.21	75.	90.	83.32	99.99	91.66	109.99	100.	120.	108.33	129.99	116.66	139.99
	.23	82.14	98.56	91.23	109.51	100.39	120.46	109.52	131.42	118.65	142.38	127.77	153.32
	.25	89.28	107.13	99.2	119.04	109.12	130.94	119.04	142.84	128.96	154.75	138.88	166.65
	.26	92.85	111.42	103.17	123.8	113.49	136.18	123.8	148.56	134.12	160.94	144.44	173.32
	.29	103.57	124.28	115.07	138.08	126.57	151.85	138.09	165.7	149.6	179.52	161.11	193.33
	.3125	111.6	133.92	124.	148.8	136.4	163.68	148.74	178.56	161.2	193.44	173.61	208.23
	.33	117.85	141.42	130.94	157.12	144.04	172.84	157.14	188.56	170.23	204.27	183.33	219.99
	.35	125.	150.	138.88	166.65	152.77	183.32	166.66	199.99	180.55	216.66	194.44	233.32
	.375	133.92	160.7	148.8	178.56	163.68	196.40	178.57	214.28	193.45	232.14	208.33	249.99
44 inches.	.1875	63.92	76.7	71.02	85.22	78.12	93.74	85.22	102.26	92.32	110.78	99.42	119.3
	.21	71.59	85.9	79.54	95.44	87.49	104.98	95.45	114.64	103.4	124.08	111.36	133.63
	.23	78.4	94.08	87.12	104.54	95.83	114.99	104.54	125.44	113.25	135.9	121.96	146.35
	.25	85.22	102.26	94.69	113.62	104.16	124.99	113.63	136.35	123.1	147.72	132.56	159.07
	.26	88.63	106.35	98.48	118.17	108.32	129.99	118.18	141.81	128.02	153.62	137.87	165.44
	.29	98.86	118.63	109.84	131.80	120.83	144.99	131.81	158.17	142.79	171.33	153.78	184.53
	.3125	106.53	127.83	118.36	142.03	130.2	156.24	142.04	170.44	153.88	184.65	165.71	198.85
	.33	112.5	135.	124.99	149.98	137.49	164.98	150.	180.	162.49	194.98	174.99	209.98
	.35	119.31	143.17	132.57	159.08	145.83	174.99	159.09	190.9	172.34	206.8	185.6	222.72
	.375	127.81	153.37	142.04	170.44	156.24	187.48	170.45	204.54	184.65	221.58	198.86	238.63
46 inches.	.1875	61.14	73.36	67.93	81.51	74.72	89.66	81.51	97.81	88.31	105.97	95.1	114.12
	.21	68.47	82.16	76.08	91.29	83.69	100.42	91.3	109.56	98.91	118.69	106.52	127.82
	.23	75.	90.	83.33	100.	91.66	109.99	100.	120.	108.33	129.99	116.66	139.99
	.25	81.51	97.81	90.57	108.68	99.63	119.55	108.69	130.42	117.75	141.3	126.8	152.16
	.26	84.78	101.73	94.2	113.04	103.62	124.34	113.44	135.64	122.46	146.95	131.88	158.25
	.29	94.56	113.47	105.07	126.	115.57	138.68	126.09	151.3	136.59	163.92	147.1	176.52
	.3125	101.9	122.28	113.21	135.86	124.54	149.44	135.86	163.03	147.19	176.62	158.51	190.21
	.33	107.6	129.12	119.56	143.47	131.52	157.82	143.97	172.16	155.43	186.51	167.39	200.86
	.35	114.13	136.95	126.8	152.16	139.49	167.38	152.17	182.6	164.85	197.82	177.53	213.03
	.375	122.28	146.73	135.86	163.03	149.45	179.34	163.04	195.64	176.62	211.94	190.21	228.25

TABLE OF PRESSURES ALLOWED ON BOILERS.—*Continued.*

Diameter of boiler.	*Thickness of plates.*	45,000 *tensile strength.* 1-6, 7,500.		50,000 *tensile strength.* 1-6, 8,333.3.		55,000 *tensile strength.* 1-6, 9,166.6.		60,000 *tensile strength.* 1-6, 10,000.		65,000 *tensile strength.* 1-6, 10,833.3.		70,000 *tensile strength.* 1-6, 11,666.6.	
		Pressure.	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*
	.1875	58.59	70.30	65.1	78.12	71.61	85.93	78.12	93.74	84.63	101.55	91.13	109.35
	.21	65.62	78.74	72.91	87.49	80.2	96.24	87.49	104.98	94.79	113.74	102.08	122.49
	.23	71.87	86.24	79.85	95.82	87.84	105.4	95.83	114.99	103.81	124.57	111.8	133.16
	.25	78.12	93.74	86.8	104.16	95.48	114.57	104.16	124.99	112.84	135.4	121.52	145.82
48 inches.	.26	81.25	97.50	90.27	108.32	99.3	119.16	108.83	129.99	117.36	140.83	126.38	151.65
	.29	90.62	108.74	100.69	120.82	110.76	132.91	120.83	144.99	130.9	157.08	140.97	169.16
	.3125	97.65	117.18	108.5	130.2	119.35	143.22	130.21	156.25	141.05	169.26	151.9	182.28
	.33	103.12	123.74	114.58	137.49	126.04	151.24	137.5	165.	148.95	178.74	160.41	192.49
	.35	109.37	131.24	121.52	145 82	133.67	160.4	145.83	174.99	157.98	189.57	170.13	204.15
	.375	117.18	140.61	130.2	156.24	143.22	171.86	156.25	187.50	169.27	203.12	182.29	218.74
	.1875	52.08	62.49	57.87	69.44	63.65	76.38	69.44	82.44	75.23	90.27	81.01	97.21
	.21	58.33	69.99	64.81	77.77	71.29	85.54	77.77	93.32	84.25	101.1	90.74	108.88
	.23	63.88	76.65	70.98	85.17	78.08	93.69	85.18	102.21	92.28	110.73	99.38	119.25
	.25	69.44	83.32	77.16	92.59	84.87	101.84	92.59	111.10	100.3	120.36	108.02	129.62
54 inches.	.26	72.22	86.66	80.24	96.28	88.27	105.92	96.29	115.54	104.31	125.17	112.44	134.8
	.29	80.55	96.66	89.5	107.40	98.45	118.14	107.41	128.88	116.35	139.62	125.3	150.36
	.3125	86.8	104.16	96.44	115.72	106.09	127.30	115.55	138.66	125.38	150.45	135.03	162.03
	.33	91.66	109.99	101.84	122.22	112.03	134.43	122.22	146.66	132.4	158.88	142.59	171.10
	.35	97.22	116.66	108.02	129.62	118.82	142.58	129.62	155.54	140.43	168.51	151.23	181.47
	.375	104.16	124.99	115.74	138.88	127.31	152.77	138.88	166.65	150.46	180.55	162.08	194.43
	.1875	46.87	56.24	52.08	62.49	57.29	68.74	62.5	75.	67.7	81.24	72.91	87.49
	.21	52.5	63.	58.33	69.99	64.16	76.99	69.99	84.	75.83	90.99	81.66	97.99
	.23	57.5	69.	63.88	76.65	70.27	84.32	76.66	91.99	83.05	99.66	89.44	107.32
	.25	62.5	75.	69.44	83.32	76.38	91.65	83.33	99.99	90.27	108.32	97.22	116.66
60 inches.	.26	65.	78.	72.22	86.66	79.44	95.32	86.66	103.99	93.58	112.65	101.11	121.33
	.29	72.5	87.	80.55	96.66	88.61	106.33	96.66	115.99	104.72	125.66	112.77	135.32
	.3125	78.12	93.74	86.8	104.16	95.48	114.57	104.18	124.99	112.95	135.54	121.52	145.82
	.33	82.5	99.	91.66	109.99	100.83	120.99	109.99	132.	119.16	142.99	128.33	153.99
	.35	87.5	105.	97.22	116.66	106.94	128.32	116.66	139.99	126.38	151.65	136.11	163.33
	.375	93.75	112.5	104.16	124.99	114.58	137.49	125.	150.	135.41	162.49	145.83	174.99

TABLE OF PRESSURES ALLOWED ON BOILERS.—*Continued.*

Diameter of boiler.	*Thickness of plates.*	45,000 *tensile strength.* 1-6, 7,500.		50,000 *tensile strength.* 1-6, 8,333.3.		55,000 *tensile strength.* 1-6, 9,166.6.		60,000 *tensile strength.* 1-6, 10,000.		65,000 *tensile strength.* 1-6, 10,833.3.		70,000 *tensile strength.* 1-6, 11,666.6.	
		Pressure.	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*
66 inches.	.1875	42.61	51.13	47.34	56.8	52.07	62.49	56.81	68.17	61.55	73.86	66.28	79.53
	.21	47.72	57.26	53.	63.63	58.33	69.99	63.63	76.35	68.93	82.71	74.24	89.08
	.23	52.27	62.72	58.	69.69	63.88	76.65	69.69	83.62	75.5	90.6	81.31	97.57
	.25	56.81	68.17	63.13	75.75	69.44	83.32	75.75	90.90	82.07	98.48	88.37	106.04
	.26	59.09	70.9	65.65	78.78	72.22	86.66	78.78	94.53	85.35	102.42	91.91	110.29
	.29	65.90	79.08	73.23	87.87	80.55	96.66	87.87	105.44	95.2	114.24	102.52	123.02
	.3125	71.	85.2	78.91	94.69	86.89	104.16	94.69	113 62	102.58	123.09	110.47	132.56
	.33	75.	90.	83.33	99.99	91.66	109.99	99.99	120	108.33	129.99	116.66	139.99
	.35	79.56	95.47	88.38	106.05	97.22	116.66	106.	127.27	114.89	137.86	123.78	148.47
	.375	85.22	102.26	94.69	113.62	104.16	124.99	113.62	136.34	123.1	147.72	132.57	159.08
72 inches.	.1875	39.06	46.87	43.4	52.08	47.74	57.28	52.08	62.49	56.42	67.70	60.76	72.91
	.21	43.75	52.5	48.6	58.33	53.47	64.16	58.33	69.99	63.19	75.82	68.05	81.66
	.23	47.91	57.49	53.24	63.88	58.56	70.27	63.88	76.65	69.21	83.05	74.53	89.43
	.25	52.08	62.49	57.87	69.44	63.65	76.38	69.44	83.32	75.22	90.26	81.01	97.21
	.26	54.16	64.99	60.18	72.21	66.2	79.44	72.22	86.66	78.24	93.88	84.25	101.10
	.29	60.41	72.49	67.12	80.54	73.84	88.60	80.55	96.66	87.26	104.71	93.98	112.77
	.3125	65.10	78.12	72.33	86.8	79.57	95.48	86.8	104.16	94.08	112.83	101.27	121.52
	.33	68.75	82.5	76.38	91.65	84.02	100.82	91.66	109.99	99.3	119.16	106.94	128.32
	.35	72.91	87.49	81.01	97.21	89.11	106.93	97.22	116.66	105.82	126.38	113.42	136.1
	.375	78.12	93.74	86.8	104.16	95.48	114.57	104.16	124.99	112.84	135.43	121.52	145.82
78 inches.	.1875	36.05	43.21	40.06	48.07	44.07	52.87	48.07	57.68	52.08	62.49	56.08	67.29
	.21	40.38	48.45	44.87	53.84	49.35	59.22	53.84	64.60	58.33	69.99	62.82	75.38
	.23	44.23	53.07	49.14	58.96	54.05	64.86	58.95	70.76	63.88	76.65	68.80	82.56
	.25	48.07	57.68	53.41	64.09	58.76	70.5	64.4	76.92	69.44	83.32	74.78	89.73
	.26	50.	60.	55.55	66.66	66.11	73.33	66.66	79.99	72.22	86.66	77.77	93.32
	.29	55.76	66.91	61.96	74.35	68.16	81.79	74.35	89.22	80.55	96.66	86.75	104.1
	.3125	60.09	72.1	66.77	80.12	73.45	88.14	80.12	96.14	86.8	104.16	93.48	112.17
	.33	63.46	76.15	70.51	84.61	77.56	93.07	84.61	101.53	91.66	109.99	98.71	118.45
	35	67.3	80.76	74.78	89.73	82.26	98.71	89.74	107.68	97.22	116.66	104.70	125.64
	.375	72.11	86.53	80.12	96.14	88.14	105.76	96.15	115.38	104.16	124.99	112.17	134.6

TABLE OF PRESSURES ALLOWED ON BOILERS.—*Continued.*

Diameter of boiler.	Thickness of plates.	45,000 *tensile strength.* 1-6, 7,500.		50,000 *tensile strength.* 1-6, 8,333.3.		55,000 *tensile strength.* 1-6, 9,166.6.		60,000 *tensile strength.* 1-6, 10,000.		65,000 *tensile strength.* 1-6, 10,833.3.		70,000 *tensile strength.* 1-6, 11,666.6.	
		Pressure.	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*
84 inches.	.1875	33.48	40.17	37.2	44.68	40.92	49.1	44.64	53.56	48.36	58.03	52.08	62.49
	.21	37.5	45.	41.66	49.99	45.83	54.99	50.	60.	54.16	64.99	58.33	69.99
	.23	41.02	49.22	45.63	54.75	50.19	60.22	54.75	65.71	59.32	71.18	63.65	76.38
	.25	44.64	53.56	49.6	59.52	54.56	65.47	59.52	71.42	64.48	77.37	69.44	83.32
	.26	46.42	55.7	51.58	61.89	56.74	68.08	61.9	74.28	67.05	80.46	72.22	86.66
	.29	51.78	62.13	57.53	69.03	63.29	75.94	69.04	82.84	74.8	89.76	80.55	96.66
	.3125	55.8	66.96	62.	74.4	68.2	81.84	74.4	89.28	80.6	96.72	86.8	104.16
	.33	58.92	70.7	65.47	78.56	72.02	86.42	78.57	94.28	85.11	102.13	91.66	109.99
	.35	62.5	75.	69.44	83.32	76.38	91.65	83.33	99.99	90.27	108.32	97.22	116.66
	.375	66.96	80.35	74.4	89.28	81.84	98.2	89 28	107.13	96.72	116.06	104.16	124.99
90 inches.	.1875	31.25	37.5	34.72	41.66	38.19	45.82	41.66	49 99	45.13	54.15	48.68	58.33
	.21	35.	42.	38.88	46.65	42.77	51.32	46.66	55.99	50.55	60.66	54.44	65.32
	.23	38.33	45.99	42.59	51.10	46.85	56.22	51.11	61.33	55.37	66.44	59.62	71.54
	.25	41.66	49.99	46.29	55.54	50.92	61.1	55.55	66 66	60.18	72.21	64.81	77.77
	.26	43.33	51.99	48.14	57.76	52.96	63.55	57.77	69.32	62.59	75.1	67.4	80.88
	.29	48.33	57.99	53.7	64.44	59.07	70.8	64 44	77.32	69.81	83.77	75.18	90.21
	.3125	52.08	62.49	57.86	69.43	63.65	76.38	69.44	83.32	75.23	90.27	81.01	97.21
	.33	55.	66	61.11	73.33	67.22	80.66	73.33	87.99	79.44	95.32	85.55	102.66
	.35	58.33	69.99	64.81	77.77	71.29	85.54	77.77	93.32	84.25	101.1	90.72	108.88
	.375	62.5	75.	69.44	83.32	76.38	91.65	83.33	99.99	90.27	108.32	97.22	116.66
96 inches.	.1875	29.29	35.14	32.55	39.06	35.8	42.96	39.06	46.87	42.31	50 77	45.57	54.68
	.21	32.81	39.37	36.45	43.74	40.1	48.12	43.75	52.5	47.39	56.86	51.04	61.24
	.23	35.93	43.11	39.93	47.91	43.92	52.7	47.91	57.49	51.9	62.28	55.9	67.08
	.25	39.06	46.87	43.4	52.08	47.74	57.28	52.08	62.49	56.42	67.67	60.76	72 91
	.26	40.62	48.74	45.14	54 16	49.65	59.58	54.16	64.99	58.78	70.53	63.19	75.82
	.29	45.31	54.37	50.34	60.4	55.38	66.45	60.41	72.49	65 45	78.54	70.48	84.57
	.3125	48.82	58 58	54.25	65.1	59.67	71.6	65.1	78 12	70.52	84.62	75.95	91.14
	.33	51.56	61.87	57 29	68.74	63.02	75.62	68.75	82.5	74.47	89.36	80.2	96.24
	.35	54.68	65.61	60.76	72.91	66.83	80.19	72.91	87.49	78.99	94.78	85 06	102.07
	.375	58.58	70.29	65.1	78.12	71.61	85.98	78.12	93.74	84.63	101.55	91.14	109.6

PRESSURE ALLOWABLE ON BOILERS.

TABLE OF PRESSURES ALLOWED UNDER THE PROVISIONS OF THE SPECIAL ACT OF CONGRESS RELATING TO THE LIMITATION OF STEAM-PRESSURE OF VESSELS USED EXCLUSIVELY FOR TOWING AND CARRYING FREIGHT ON THE MISSISSIPPI RIVER AND ITS TRIBUTARIES, APPROVED JANUARY 6, 1874.

Thickness of iron.	34 *ins. diam.*	36 *ins. diam.*	38 *ins. diam.*	40 *ins. diam.*	42 *ins. diam.*	44 *ins. diam.*	46 *ins. diam.*	48 *ins. diam.*	50 *ins. diam.*	52 *ins. diam.*	54 *ins. diam.*	56 *ins. diam.*	58 *ins. diam.*	60 *ins. diam.*
Inches.	Pds.	Pds.	Pds.	Pds.	Pds.	Pds.	Pds.	Pds.	Pds.	Pds.	Pds.	Pds.	Pds.	Pds.
.19	140.82	133.	126.	119.70	114.	108.81	104.08	99.75	95.75	92.07	88.66	85.50	82.55	79.80
.20	148.23	140.	132.63	126.	120.	114.54	109.56	105.	100.80	96.92	93.33	90.	86.90	84.
.21	155.64	147.	139.26	132.30	126.	120.27	115.04	110.25	105.84	101.77	98.	94.50	91.24	88.20
.22	163.05	154.	149.50	138.60	132.	126.	120.52	115.50	111.08	106.81	102.66	99.	95.69	92.40
.23	170.47	161.	152.52	144.90	138.	131.72	126.	120.75	115.92	111.46	107.33	103.50	99.93	96.60
.24	177.88	168.	159.15	151.20	144.	137.45	131.47	126.	120.95	117.07	112.	108.	104.27	100.80
.25	185.29	175.	165.79	157.50	150.	143.18	136.95	131.25	126.	121.15	116.66	112.50	108.62	105.
.26	192.70	182.	172.42	163.80	156.	148.80	142.43	136.50	131.04	126.	121.33	117.	113.	109.20
.27	200.11	189.	179.05	170.10	162.	154.63	147.91	141.75	136.08	130.84	126.	121.50	117.31	113.40
.28	207.53	191.	185.68	176.40	168.	160.36	152.52	147.	141.11	135.69	130.66	126.	121.65	117.60
.29	214.94	203.	192.31	182.70	174.	166.04	158.87	152.25	146.16	140.53	134.25	130.50	126.	121.80
.30	222.35	210.	198.94	189.	180.	171.81	164.34	157.50	151.50	145.38	140.	135.	130.34	126.
.31	229.76	217.	205.57	195.30	186.	177.54	169.82	162.75	156.24	150.23	144.66	139.50	134.68	130.

The above table gives the steam-pressure allowed on boilers used on freight and towing steamers, the standard pressure being 150 pounds for a boiler 42 inches diameter and .25 of an inch thick. To find the pressure required on other size boilers (not given in the above table), multiply 12,600 by the thickness and divide by the radius, or half the diameter.

The U. S. rule for finding the dimension of boilers is as follows: RULE.—Multiply one-sixth (1-6) of the lowest tensile strength found stamped on any plate in the cylindrical shell by the thickness (expressed in inches or parts of an inch) of the thinnest plate in the same cylindrical shell, and divide by the radius, or half diameter (also expressed in inches), and the quotient will be the pressure allowable per square inch of surface for single riveting, to which add twenty per centum for double riveting, etc.

TABLE SHOWING WATER AND COAL REQUIRED FOR STEAM-POWER.

H. P.	*Water in Gals. per hour.*	*Coal req'd in lbs. per hour.*	*Water in Gals. per day of 10 hrs.*	*Coal in lbs. per day of 10 hrs.*
5	20	20	200	200
10	41	40	410	400
15	58	60	580	600
20	72	80	720	800
25	90	100	900	1,000
30	110	120	1,100	1,200
40	145	160	1,450	1,600
50	180	200	1,800	2,000
60	220	240	2,200	2,400
70	260	280	2,600	2,800
80	290	320	2,900	3,200
100	405	400	4,050	4,000
125	450	500	4,500	5,000
150	590	600	5,900	6,000
200	725	800	7,250	8,000
250	900	1,000	9,000	10,000

RATE OF COMBUSTION OF COAL IN BOILER FURNACES.

Kind of Boiler.	*Lbs. per sq. ft. of grate per hour.*
Lowest rate of Combustion in Cornish Boilers.........	4
Usual rate in Cornish Boilers	10
Usual rate in Factory Boilers.......................	10 to 18
Usual rate in Marine Boilers.......................	14 to 26
Usual rate in Locomotive Boilers (with blast-pipe) ..	60 to 130

LIST OF BOOKS AND AUTHORS.

PERMANENT WAY OF EUROPEAN RAILWAYS, Zerah Colburn and A. L. Holley.

COMBUSTION OF COAL AND PREVENTION OF SMOKE, Chas. Wye Williams.

TREATISE ON STEAM BOILER INCRUSTATIONS, Chas. T. Davis.

TREATISE ON STEAM BOILERS, T. Wilson.

RAPPORT DE L' ASSOCIATION POUR LA SURVEILLANCE DES CHAUDIÈRES À VAPEUR, Brussels.

STEAM MAKING, Prof. Chas. A. Smith.

RESEARCHES IN STEAM ENGINEERING, B. F. Isherwood, U. S. N.

CATECHISM OF THE LOCOMOTIVE, M. L. Forney.

MARINE BOILERS, N. P. Burgh.

"ENGINEERING"— London.

"AMERICAN ENGINEER"— Chicago.

SERVIMUS SERVARE

Principal Office, No. 45 William Street.

DIRECTORS.

This Company is managed by the following Board of Directors:

Hon. Felix Campbell, Engineer and Iron Merchant, 79 John Street, New-York City.

Herman Winter, Engineer, Morgan's Louisiana and Texas Railroad and Steamship Company, New-York City.

John M. Jones, of Messrs. Gantz, Jones & Co., 176 Duane Street, New-York City.

Stephen R. Lesher, of Messrs. Lesher, Whitman & Co., 502 Broadway, New-York City.

Wm. A. Scott, of Messrs. Lothrop & Scott, Insurance Managers, 170 Broadway, New-York City.

William Arrott, Insurance Manager, 115 South Fourth Street, Philadelphia, Pa.

William Wood, of Messrs. William Wood & Co., Philadelphia, Pa.

William G. Park, of Messrs. Park Brothers & Co., Pittsburgh, Pa.

John H. Flagler, of National Tube Works Company, McKeesport, Pa., and 104 John Street, New-York.

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Hon. William Brinkerhoff, No. 1 Exchange Place, Jersey City, N. J.

Edward P. Haslam, Retired Merchant, Jersey City, N. J.

William Henry Jackson, Retired Merchant, Newtown, Long Island, New-York.

William K. Lothrop, President of Company.

William E. Midgley, Vice-President of Company.

Vincent R. Schenck, Secretary of Company.

Sewell, Pierce & Sheldon, Counsel to Company.

ANNUAL STATEMENT, Jan. 1, 1886,

OF THE

American Steam Boiler Insurance Co.

ORGANIZED, NOV. 5, 1883.

NO CONTESTED CLAIMS.

All Losses
have been paid in full
within ten days,
without discount.

ASSETS.

Jan. 1, '84, $197,724.41

March 1, '84, $195,410.57

May 1, 1884, $195,914.70

July 1, '84. $199,023.71

Sept. 1, '84. $199,948.97

Nov. 1, 1884, $212,314.33

Jan. 1, 1885, $243,694.33

March 1, 1885, $244,351.68

May 1, 1885, $261,676.94

July 1, 1885, $272,292.96

Sept. 1, 1885. $273,099.61

Nov. 1, 1885, $288,628.38

January 1, 1886,

* $304,836.53 *

Feb. 25, 1886.
The Directors on this date
increased the Capital Stock to
$500,000,
thus making the
"American"
the largest Steam Boiler
Insurance Company
in the world.

ASSETS, CONSISTING OF:

U. S. Gov't 4½ Registered Bonds	**$248,050.00**
Cash on hand and in bank	**13,166.04**
Net Premiums in course of collection	**43,620.49**
	$304,836.53

TABLE OF PRESSURES ALLOWABLE ON BOILERS.

Diameter of boiler.	*Thickness of plates.*	45,000 *tensile strength.* 1-6, 7,500.		50,000 *tensile strength.* 1-6, 8,333.3.		55,000 *tensile strength.* 1-6, 9,166.6.		60,000 *tensile strength.* 1-6, 10,000.		65,000 *tensile strength.* 1-6, 10,833.3.		70,000 *tensile strength.* 1-6, 11,666.6.	
		Pressure.	20 *per ct. additional.*	*Pressure.*	20 *per ct. additional.*	*Pressure.*	20 *per ct. additional.*	*Pressure.*	20 *per ct. additional.*	*Pressure.*	20 *per ct. additional.*	*Pressure.*	20 *per ct. additional.*
	.1875	78.12	93.74	86.8	104.16	95.48	114.57	104.16	124.99	112.84	135.4	121 52	145.82
	.21	87.5	105.	97.21	116.65	106.94	128.3	116.66	139.99	126.38	151.65	136.11	163 33
	.23	95.83	114.99	106.47	127.76	117.12	140.54	127.77	153.32	138.41	166.09	149 07	178.88
	.25	104.16	124.99	115.74	138.88	127.31	152.77	138.88	166.65	150.46	180.55	162.03	194.43
36 inches.	.26	108.33	129.99	120.37	144.44	132.4	158.88	144.44	173.32	156.48	187.77	168.51	202.21
	.29	120.83	144.99	134.25	161.11	147.68	177.21	161.11	193.33	174.53	209.43	187.90	225.48
	.3125	130.2	156.24	144.67	173.6	159.14	190.96	173.6	208.32	188.07	225.68	202.5	243.04
	.33	137.5	165.	152.77	183.32	168.05	201.66	183.33	219.99	198.61	238.33	213.88	256.65
	.35	145.83	174.99	162.03	194.43	178.23	213.87	194.44	233.32	210.64	252.76	226.84	272.20
	.375	156.25	187·5	173.61	208.33	190.97	229.16	208.33	249.99	225.69	271.82	243.05	291.66
	.1875	74.01	88.89	82.23	98.67	90.46	108.54	98.68	118 41	106.9	128.28	115.13	138.16
	.21	82.89	99.46	92.1	110.52	101.31	121.57	110.52	132.62	119.73	143.67	128.93	154.71
	.23	90.78	108.93	100.87	121.04	110.96	133.15	121.05	145.26	131.13	157.35	141.22	169.46
	.25	98.68	118.41	109.64	131.56	120.61	144.73	131.57	157.88	142 54	171.04	153.5	184.20
38 inches.	.26	102.63	123.15	114.03	136.83	125.43	150.51	136.84	164.2	148.24	177.88	159.64	191.56
	.29	114.47	137.36	127.19	152.62	139.91	167.89	152.63	183.15	165.35	198.42	178.06	213.67
	.3125	123.35	148.02	137.	164.46	150.76	180.91	164.47	197.36	178.17	213.8	191.88	230.25
	.33	130.26	156.31	144.73	173.67	159.2	191.04	173.68	208.41	188.15	225.78	202 62	243.14
	.35	138.15	165.78	153.5	184.21	168.85	202.62	184.21	221.05	199.56	239.47	214.91	257.89
	.375	148.	177.60	164.73	197.67	180.91	217.09	197.36	236.83	213.81	256.57	230.26	276.31
	.1875	70.31	84.37	78.12	93.74	85.93	103.11	93.75	112.5	101.56	121.87	109.37	131.24
	.21	78.75	94.50	87.49	104.98	96.24	115.48	105.	126.	113.74	136.48	122.49	146.98
	.23	86.25	103.5	95.83	114.99	105.41	126.49	115.	138.	124.58	149.49	134.16	160.99
	.25	93.75	112.5	104.16	124.99	114.58	137.49	125.	150.	135.41	162.49	145.83	174.99
40 inches.	.26	97.5	117.	108.33	129.99	119.16	142.99	130	156.	140.83	168.99	151.66	181.99
	.29	108.75	130.5	120.83	144.99	132.91	159.49	145.	174.	157.08	188.49	169.16	202.99
	.3125	117.18	140.61	130.2	156.24	143.22	171.86	156.25	187.45	169.27	203.12	182.29	218.74
	.33	123.75	148.5	137.49	164.98	151 24	181.48	165.	198.	178.74	214.48	192.49	230.98
	.35	131.25	157.5	145.83	174.99	160.41	192.49	175.	210.	189.58	227.49	204.16	244.99
	.375	140.62	168.74	156.24	187.48	171.87	206 24	187.5	225.	203.12	243.74	218.74	262.48

TABLE OF PRESSURES ALLOWABLE ON BOILERS.— *Continued.*

Diameter of boiler.	Thickness of plates.	45,000 *tensile strength.* 1-6, 7,500.		50,000 *tensile strength.* 1-6, 8,333.3.		55,000 *tensile strength.* 1-6, 9,166.6.		60,000 *tensile strength.* 1-6, 10,000.		65,000 *tensile strength.* 1-6, 10,833.3.		70,000 *tensile strength.* 1-6, 11,666.6.	
		Pressure.	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*
42 inches.	.1875	66.96	80.35	74.40	89.28	81.84	98.20	89.28	107.13	96.72	116.06	104.16	124.99
	.21	75.	90.	83.32	99.99	91.66	109.99	100.	120.	108.33	129.99	116.66	139.99
	.23	82.14	98.56	91 23	109.51	100.39	120.46	109.52	131.42	118.65	142.38	127.77	153.32
	.25	89.28	107.13	99.2	119.04	109.12	130.94	119.04	142.84	128.96	154.75	138.88	166.65
	.26	92.85	111.42	103.17	123.8	113.49	136.18	123.8	148.56	134.12	160.94	144.44	173.32
	.29	103.57	124 28	115.07	138.08	126.57	151.85	138.09	165.7	149.6	179.52	161.11	193.33
	.3125	111.6	133.92	124.	148.8	136.4	163.68	148.74	178.56	161.2	193.44	173.61	208.23
	.33	117.85	141.42	130.94	157.12	144.04	172.84	157.14	188.56	170.23	204.27	183.33	219.99
	.35	125.	150.	138.88	166.65	152.77	183.32	166.66	199.99	180.55	216.66	194.44	233.32
	.375	133.92	160.7	148.8	178.56	163.68	196.40	178.57	214.28	193.45	232.14	208.33	249.99
44 inches.	.1875	63.92	76.7	71.02	85.22	78.12	93.74	85.22	102.26	92.32	110.78	99.42	119.3
	.21	71.59	85.9	79.54	95.44	87.49	104.98	95.45	114.64	103.4	124.08	111.36	133.63
	.23	78.4	94.08	87.12	104.54	95.83	114.99	104.54	125.44	113.25	135.9	121.96	146.35
	.25	85.22	102.26	94.69	113.62	104.16	124.99	113.63	136.35	123.1	147 72	132.56	159.07
	.26	88.63	106.35	98.48	118 17	108.33	129.99	118.18	141.81	128.02	153.62	137.87	165.44
	.29	98.86	118.63	109.84	131.80	120.83	144.99	131.81	158 17	142.79	171.33	153.78	184.53
	.3125	106.53	127.83	118.36	142.03	130.2	156.24	142.04	170.44	153 88	184.65	165.71	198.85
	.33	112.5	135.	124.99	149.98	137.49	164.98	150.	180.	162.49	194.98	174.99	209.98
	.35	119.31	143.17	132.57	159.08	145.83	174.99	159.09	190 9	172 34	206.8	185.6	222.72
	.375	127.81	153.37	142.04	170.44	156.24	187.48	170.45	204.54	184.65	221.58	198.86	238.63
46 inches.	.1875	61.14	73.36	67.93	81.51	74.72	89.66	81.51	97.81	88.31	105.97	95.1	114.12
	.21	68.47	82.16	76.08	91.29	83.69	100.42	91.3	100 56	98.91	118.69	106.52	127.82
	.23	75.	90.	83.33	100.	91.66	109.99	100.	120.	108.33	129.99	116.66	139.99
	.25	81.51	97.81	90.57	108.68	99.63	119.55	108.69	130.42	117.75	141.3	126.8	152.16
	.26	84.78	101.73	94.2	113.04	103.62	124.34	113.44	135.64	122.46	146.95	131.88	158.25
	.29	94.56	113.47	105.07	126.	115.57	138.68	126.09	151.3	136.59	163.92	147.1	176.52
	.3125	101.9	122.28	113.21	135.86	124.54	149.44	135.86	163.03	147.19	176.62	158.51	190.21
	.33	107.6	129.12	119.56	143.47	131.52	157 82	143.97	172.16	155.43	186.51	167.39	200.86
	.35	114.13	136.95	126.8	152.16	139.49	167.38	152.17	182.6	164.85	197.82	177.53	213.03
	.375	122.28	146.73	135.86	163.03	149.45	179.34	163.04	195.64	176.62	211.94	190.21	228.25

TABLE OF PRESSURES ALLOWED ON BOILERS.—*Continued.*

Diameter of boiler.	Thickness of plates.	45,000 *tensile strength.* 1-6, 7,500.		50,000 *tensile strength.* 1-6, 8,333.3.		55,000 *tensile strength.* 1-6, 9,166.6.		60,000 *tensile strength.* 1-6, 10,000.		65,000 *tensile strength.* 1-6, 10,833.3.		70,000 *tensile strength.* 1-6, 11,666.6.	
		Pressure.	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*
	.1875	58.59	70.30	65.1	78.12	71.61	85.93	78.12	93.74	84.63	101.55	91.13	109.35
	.21	65.62	78.74	72.91	87.49	80.2	96.24	87.49	104.98	94.79	113.74	102.08	122.49
	.23	71.87	86.24	79.85	95.82	87.84	105.4	95.83	114.99	103.81	124.57	111.8	133.16
	.25	78.12	93.74	86.8	104.16	95.48	114.57	104.16	124.99	112.84	135.4	121.52	145.82
48 inches.	.26	81.25	97.50	90.27	108.32	99.3	119.16	108.33	129.99	117.36	140.83	126.38	151.65
	.29	90.62	108.74	100.69	120.82	110.76	132.91	120.83	144.99	130.9	157.08	140.97	169.16
	.3125	97.65	117.18	108.5	130.2	119.35	143.22	130.21	156.25	141.05	169.26	151.9	182.28
	.33	103.12	123.74	114.58	137.49	126.04	151.24	137.5	165.	148.95	178.74	160.41	192.49
	.35	109.37	131.24	121.52	145.82	133.67	160.4	145.83	174.99	157.98	189.57	170.13	204.15
	.375	117.18	140.61	130.2	156.24	143.22	171.86	156.25	187.50	169.27	203.12	182.29	218.74
	.1875	52.08	62.49	57.87	69.44	63.65	76.38	69.44	82.44	75.23	90.27	81.01	97.21
	.21	58.33	69.99	64.81	77.77	71.29	85.54	77.77	93.32	84.25	101.1	90.74	108.88
	.23	63.88	76.65	70.98	85.17	78.08	93.69	85.18	102.21	92.28	110.73	99.38	119.25
	.25	69.44	83.32	77.16	92.59	84.87	101.84	92.59	111.10	100.3	120.36	108.02	129.62
54 inches.	.26	72.22	86.66	80.24	96.28	88.27	105.92	96.29	115.54	104.31	125.17	112.44	134.8
	.29	80.55	96.66	89.5	107.40	98.45	118.14	107.41	128.88	116.35	139.62	125.3	150.36
	.3125	86.8	104.16	96.44	115.72	106.09	127.30	115.55	138.66	125.38	150.45	135.03	162.03
	.33	91.66	109.99	101.84	122.22	112.03	134.43	122.22	146.66	132.4	158.88	142.59	171.10
	.35	97.22	116.66	108.02	129.62	118.82	142.58	129.62	155.54	140.43	168.51	151.23	181.47
	.375	104.16	124.99	115.74	138.88	127.31	152.77	138.88	166.65	150.46	180.55	162.08	194.43
	.1875	46.87	56.24	52.08	62.49	57.29	68.74	62.5	75.	67.7	81.24	72.91	87.49
	.21	52.5	63.	58.33	69.99	64.16	76.99	69.99	84.	75.83	90.99	81.66	97.99
	.23	57.5	69.	63.88	76.65	70.27	84.32	76.66	91.99	83.05	99.66	89.44	107.32
	.25	62.5	75.	69.44	83.32	76.38	91.65	83.33	99.99	90.27	108.32	97.22	116.66
60 inches.	.26	65.	78.	72.22	86.66	79.44	95.32	86.66	103.99	93.58	112.65	101.11	121.33
	.29	72.5	87.	80.55	96.66	88.61	106.33	96.66	115.99	104.72	125.66	112.77	135.32
	.3125	78.12	93.74	86.8	104.16	95.48	114.57	104.18	124.99	112.95	135.54	121.52	145.82
	.33	82.5	99.	91.66	109.99	100.83	120.99	109.99	132.	119.16	142.99	128.33	153.99
	.35	87.5	105.	97.22	116.66	106.94	128.32	116.66	139.99	126.38	151.65	136.11	163.33
	.375	93.75	112.5	104.16	124.99	114.58	137.49	125.	150.	135.41	162.49	145.83	174.99

TABLE OF PRESSURES ALLOWED ON BOILERS.—*Continued.*

Diameter of boiler.	Thickness of plates.	45,000 tensile strength. 1-6, 7,500.		50,000 tensile strength. 1-6, 8,333.3.		55,000 tensile strength. 1-6, 9,166.6.		60,000 tensile strength. 1-6, 10,000.		65,000 tensile strength. 1-6, 10,833.3.		70,000 tensile strength. 1-6, 11,666.6.	
		Pressure.	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*
	.1875	42.61	51.13	47.34	56.8	52.07	62.49	56.81	68.17	61.55	73.86	66.28	79.53
	.21	47.72	57.26	53.	63.63	58.33	69.99	63.63	76.35	68.93	82.71	74.24	89.08
	.23	52.27	62.72	58.	69.69	63.88	76.65	69.69	83.62	75.5	90.6	81.31	97.57
	.25	56.81	68.17	63.13	75.75	69.44	83.32	75.75	90.90	82.07	98.48	88.37	106.04
66 inches.	.26	59.09	70.9	65.65	78.78	72.22	86.66	78.78	94.53	85.35	102.42	91.91	110.29
	.29	65.90	79.08	73.23	87.87	80.55	96.66	87.87	105.44	95.2	114.24	102.52	123.02
	.3125	71.	85.2	78.91	94.69	86.89	104.16	94.69	113.62	102.58	123.09	110.47	132.56
	.33	75.	90.	83.33	99.99	91.66	109.99	99.99	120.	108.33	129.99	116.66	139.99
	.35	79.56	95.47	88.38	106.05	97.22	116.66	106.	127.27	114.89	137.86	123.73	148.47
	.375	85.22	102.26	94.69	113.62	104.16	124.99	113.62	136.34	123.1	147.72	132.57	159.08
	.1875	39.06	46.87	43.4	52.08	47.74	57.28	52.08	62.49	56.42	67.70	60.76	72.91
	.21	43.75	52.5	48.6	58.33	53.47	64.16	58.33	69.99	63.19	75.82	68.05	81.66
	.23	47.91	57.49	53.24	63.88	58.56	70.27	63.88	76.65	69.21	83.05	74.53	89.43
	.25	52.08	62.49	57.87	69.44	63.65	76.38	69.44	83.32	75.22	90.26	81.01	97.21
72 inches.	.26	54.16	64.99	60.18	72.21	66.2	79.44	72.22	86.66	78.24	93.88	84.25	101.10
	.29	60.41	72.49	67.12	80.54	73.84	88.60	80.55	96.66	87.26	104.71	93.98	112.77
	.3125	65.10	78.12	72.33	86.8	79.57	95.48	86.8	104.16	94.08	112.83	101.27	121.52
	.33	68.75	82.5	76.38	91.65	84.02	100.82	91.66	109.99	99.3	119.16	106.94	128.32
	.35	72.91	87.49	81.01	97.21	89.11	106.93	97.22	116.66	105.32	126.38	113.42	136.1
	.375	78.12	93.74	86.8	104.16	95.48	114.57	104.16	124.99	112.84	135.43	121.52	145.82
	.1875	36.05	43.21	40.06	48.07	44.07	52.87	48.07	57.68	52.08	62.49	56.08	67.29
	.21	40.38	48.45	44.87	53.84	49.35	59.22	53.84	64.60	58.33	69.99	62.82	75.38
	.23	44.23	53.07	49.14	58.96	54.05	64.86	58.95	70.76	63.88	76.65	68.80	82.56
	.25	48.07	57.68	53.41	64.09	58.76	70.5	64.4	76.92	69.44	83.32	74.78	89.73
78 inches.	.26	50.	60.	55.55	66.66	66.11	73.33	66.66	79.99	72.22	86.66	77.77	93.32
	.29	55.76	66.91	61.96	74.35	68.16	81.79	74.35	89.22	80.55	96.66	86.75	104.1
	.3125	60.09	72.1	66.77	80.12	73.45	88.14	80.12	96.14	86.8	104.16	93.48	112.17
	.33	63.46	76.15	70.51	84.61	77.56	93.07	84.61	101.53	91.66	109.99	98.71	118.45
	.35	67.3	80.76	74.78	89.73	82.26	98.71	89.74	107.68	97.22	116.66	104.70	125.64
	.375	72.11	86.53	80.12	96.14	88.14	105.76	96.15	115.38	104.16	124.99	112.17	134.6

TABLE OF PRESSURES ALLOWED ON BOILERS.—*Continued.*

Diameter of boiler.	Thickness of plates.	45,000 *tensile strength.* 1-6, 7,500.		50,000 *tensile strength.* 1-6, 8,333.3.		55,000 *tensile strength.* 1-6, 9,166.6.		60,000 *tensile strength.* 1-6, 10,000.		65,000 *tensile strength.* 1-6, 10,833.3.		70,000 *tensile strength.* 1-6, 11,666.6.	
		Pressure.	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*	*Pressure.*	*20 per ct. additional.*
84 inches.	.1875	33.48	40.17	37.2	44.68	40.92	49.1	44.64	53 56	48.36	58.03	52.08	62.49
	.21	37.5	45.	41.66	49.99	45.83	54.99	50.	60.	54.16	64.99	58.33	69.99
	.23	41.02	49.22	45.63	54.75	50.19	60.22	54.75	65.71	59.32	71.18	63.65	76.38
	.25	44.64	53.56	49.6	59.52	54.56	65.47	59.52	71.42	64.48	77.37	69.44	83.32
	.26	46.42	55.7	51.58	61.89	56.74	68.08	61.9	74.28	67.05	80.46	72.22	86.66
	.29	51.78	62.13	57.53	69.03	63.29	75.94	69.04	82.84	74.8	89.76	80.55	96.66
	.3125	55.8	66.96	62.	74.4	68.2	81.84	74.4	89.28	80.6	96.72	86.8	104.16
	.33	58.92	70.7	65.47	78.56	72.02	86.42	78.57	94.28	85.11	102.13	91.66	109.99
	.35	62.5	75.	69.44	83.32	76.88	91.65	83.33	99.99	90.27	108.32	97.22	116.66
	.375	66.96	80.35	74.4	89.28	81.84	98 2	89.28	107.13	96.72	116.06	104.16	124.99
90 inches.	.1875	31.25	37.5	34.72	41.66	38.19	45.82	41.66	49.99	45.13	54.15	48.68	58 33
	.21	35.	42.	38.88	46.65	42.77	51.32	46.66	55.99	50.55	60.66	54.44	65.32
	.23	38.33	45.99	42.59	51.10	46.85	56.22	51.11	61.33	55.37	66.44	59.62	71.54
	.25	41.66	49.99	46.29	55.54	50.92	61.1	55.55	66 66	60.18	72.21	64.81	77.77
	.26	43.33	51.99	48.14	57.76	52.96	63.55	57.77	69.32	62.59	75.1	67.4	80.88
	.29	48.33	57.99	53.7	64.44	59.07	70.8	64 44	77.32	69.81	83.77	75.18	90.21
	.3125	52.08	62.49	57.86	69.43	63 65	76.38	69.44	83.32	75.23	90.27	81.01	97.21
	.33	55.	66	61.11	73.33	67.22	80.66	73.33	87.99	79.44	95.32	85.55	102.66
	.35	58.33	69.99	64.81	77.77	71.29	85.54	77.77	93.32	84.25	101.1	90.72	108.88
	.375	62.5	75.	69.44	83.32	76.38	91.65	83.33	99.99	90.27	108.32	97.22	116.66
96 inches.	.1875	29.29	35.14	32.55	39.06	35.8	42.96	39.06	46.87	42.31	50 77	45.57	54.68
	.21	32.81	39.37	36.45	43.74	40.1	48.12	43.75	52.5	47.39	56.86	51.04	61.24
	.23	35.93	43.11	39.93	47.91	43.92	52.7	47.91	57.49	51.9	62.28	55.9	67.08
	.25	39.06	46.87	43.4	52.08	47.74	57.28	52.08	62.49	56.42	67.67	60.76	72.91
	.26	40.62	48.74	45.14	54 16	49.65	59.58	54.16	64.99	58.78	70.53	63.19	75.82
	.29	45.31	54.37	50.34	60.4	55.38	66.45	60.41	72.49	65.45	78.54	70.48	84.57
	.3125	48.82	58 58	54.25	65 1	59.67	71.6	65.1	78.12	70.52	84.62	75.95	91.14
	.33	51.56	61.87	57.29	68.74	63.02	75.62	68.75	82.5	74.47	89.36	80.2	96.24
	.35	54.68	65.61	60.76	72.91	66.83	80.19	72.91	87.49	78.99	94.78	85 06	102.07
	.375	58.58	70.29	65.1	78.12	71.61	85.93	78.12	93.74	84.63	101.55	91.14	109.6

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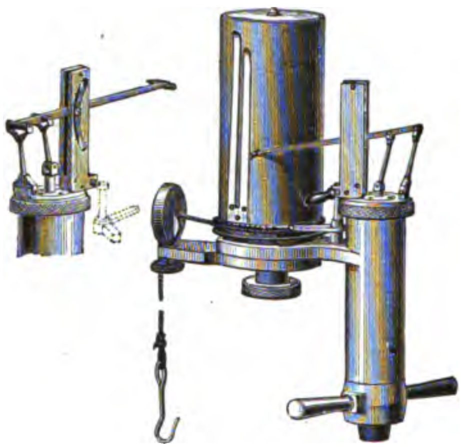

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